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# Public Roads

## A JOURNAL OF HIGHWAY RESEARCH

*Annual road costs are computed from Texas highway control section records*

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# Public Roads

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## IN THIS ISSUE





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BUREAU OF PUBLIC ROADS
U. S. DEPARTMENT OF COMMERCE
*E. A. STROMBERG, Editor*

# A Procedure for Determining the Annual Cost of a Section of Rural Highway

***BY THE FINANCIAL AND ADMINISTRATIVE RESEARCH BRANCH BUREAU OF PUBLIC ROADS***

**Reported by HAROLD W. HANSEN, Highway Engineer**

***Following its initial construction, every highway generates a demand upon current revenue for maintenance and operation and upon future revenue for rebuilding and modernization. In order that this demand may be met in a plan that will provide maximum service at minimum cost, it is essential to have knowledge of annual road costs. Such cost information is invaluable for planning and programing and, when correlated with traffic volumes, weights, surface types, and similar factors, is useful in a variety of economic analyses.***

IN RECENT YEARS a number of State highway departments have established highway control sections [1] as a means of coordinating records of the work performed on highways. Among the objectives involved in such undertakings is the bringing together of construction expenditures and maintenance and operation expenditures in a fashion that will establish a current and continuing record of the annual cost of each section of highway.

Such cost information, when available for the entire highway system, will provide a wealth of facts concerning the costs of providing road transportation service. Data pertaining to the annual cost of each type of surface, each type of structure, and other elements of the highway can be made available as a routine, continuing process in those States operating on a control-section basis. From such information on the cost of highways under a variety of conditions can be obtained the facts useful in short- and long-range planning and programing, and in numerous types of economic analyses and problems of economic justification.

### *Annual Road Cost*

The term "annual road cost" as used in the following discussion refers only to the actual or estimated annual depreciation charge plus the annual expenditure for maintenance and operation. In accord with present-day accounting practice these two cost elements would be considered essential to any method of computing annual road costs.

The depreciation charge is a measure of the annual capital (construction) cost. The expenditure for maintenance and operation indicates what has been spent to preserve the highway as nearly as possible in its original condition as constructed or as subsequently improved, and for the operation of highway facilities and services to provide satisfactory and safe highway transportation.

Other elements of highway cost, such as interest, taxes, and the like, may be included in the term annual road cost depending on the use to be made of the cost information.[2] These items have been omitted from this discussion but could, if needed, be added to the costs obtained as described here.

The procedures outlined in this report have been discussed with members of State highway planning surveys, engineers, accountants, and highway officials in more than 20 States. This material has also been discussed by members of the Highway Research Board Committee on Highway Costs [3] at the twenty-eighth and twenty-ninth annual meetings of the Highway Research Board (1948 and 1949). The suggestions and advice received as a result of these discussions are gratefully acknowledged. Special recognition is due the Texas Highway Planning Survey for its cooperation in furnishing the basic data which were used to prepare the road cost charts exhibited in this report.

### *Depreciation*

There are many mathematical formulas which can be utilized in computing depreciation charges. Some of the better known include the straight-line, production, compound-interest, sinking-fund, annuity, and fixed-percentage-of-declining-balance methods. There are others which are not as well known. In spite of the diversity of formulas the straight-line method is in almost universal use throughout the United States.[4] The principles of this method have been adapted to the determination of annual road costs.

For such purposes the funds which have been expended (invested) for the construction of highways are subdivided into various fixed-asset accounts. There are eight such fixed-asset accounts recommended by the Subcommittee on Uniform Accounting of the American Association of State Highway Officials: (1) Right-of-way, (2) roadway and drainage grading and earthwork, (3) drainage structures and roadway earthwork protective structures, (4) roadway surface and base (by roadway surface type), (5) improved shoulders and approach surfacing, (6) bridges, viaducts, grade-separation structures, and tunnels (by individual structure), (7) traffic and pedestrian services, and (8) roadside development.

For purposes of an annual cost computation, the basic information required for each control section includes date of construction, cost of construction (by fixed-asset accounts), amount depleted (or, conversely, the amount salvaged) at the time of each subsequent reconstruction, age at the time of reconstruction, and other facts. As used here, depletion refers to that portion of the construction investment which is lost at the time of reconstruction, aban-

[1] Report of the Highway Research Board Committee on Highway Costs, Memorandum No. 1. Highway Research Correlation Service Circular No. 61, May 1949.

[2] For a discussion of this subject, see *Costs of highways to the public and uses of cost computations*, Report of the Highway Research Board Committee on Highway Costs: Proceedings of the 24th annual meeting of the Highway Research Board, 1944; page 1.

[3] The members of this committee are Fred B. Farrell, *chairman*, Chief, Highway Cost Section, Bureau of Public Roads; James A. Foster, Highways and Municipal Bureau, Portland Cement Association; Carl E. Fritts, Director, Highways Division, Automotive Safety Foundation; Raleigh W. Gamble, Superintendent, Bureau of Street Construction and Repairs, Milwaukee, Wisc.; O. L. Kipp, Chief Engineer, Minnesota Department of Highways; Bertram H. Lindman, Transportation Consultant, Washington, D. C.; H. R. Wilson, Fiscal Manager, Finance and Management Division, Bureau of Public Roads; and Robley Winfrey, Research Professor of Civil Engineering, Iowa State College.

[4] *Report of Committee on Depreciation*, National Association of Railroad and Utilities Commissioners, 1943, page 89. Published by the Association, Washington, D. C.

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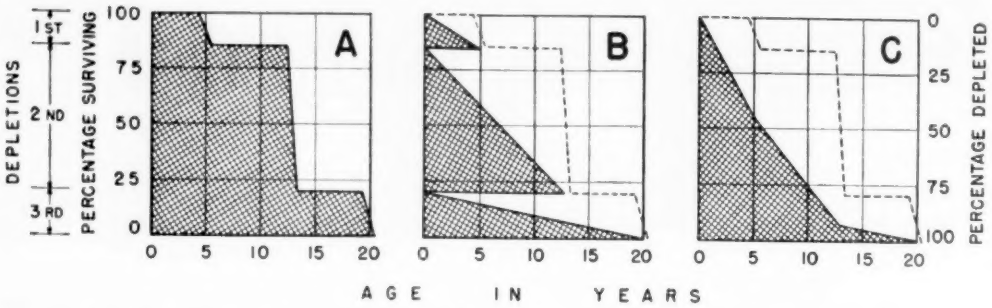



***Figure 1.**—A simple survivor curve, showing the age of the original investment at the time of each reconstruction and the amount of capital depleted, and the steps involved in deriving the combined straight-line depreciation curve.*

donment, or transfer of the highway to another authority.[5]

This basic information can be used to construct for each fixed asset the type of graph shown in figure 1A, which was made by plotting the percentage of the original investment surviving at ½, 1½, 2½, etc., years of age and then connecting these points with straight lines, a standard practice in mortality studies of highways. The resulting curve shows the survivor history of the capital invested in a given year for the construction of one of the fixed assets (roadway and drainage grading and earthwork, drainage structures and roadway earthwork protective structures, each roadway surface and base type, etc.) comprising the highway. Such graphs can be prepared for the capital invested in each of the other fixed assets, and for additional capital invested when the highway is subsequently reconstructed. The total annual depreciation charge for the control section is built up from data computed from these individual investment survivor curves.

### *Depreciation Rate*

To determine the rate of depreciation for a fixed asset having the survivor history indicated in figure 1A, each depletion is treated as a separate unit of property and the rate of depreciation for each depletion is found. Then the several rates of depreciation are added together to give the total rate of depreciation for that fixed asset. This is known as the unit summation method[6] for applying the principle of straight-line depreciation to a property group consisting of units having different service lives.

Figure 1B illustrates the first step in this procedure, that of determining the rate of depreciation for the individual depletions. The first reconstruction, 5 years after the initial construction, caused a depletion of 15 percent of the fixed asset. Accordingly, 15 percent of the fixed asset must be depreciated over a period of 5 years, which is the equivalent of an annual rate of 3 percent. Similarly, for the second depletion 65 percent is depreciated over a 13-year period, or an annual rate of 5 percent, and for the third depletion 20 percent is depreciated over 20 years, or 1 percent per year.

The manner by which the several rates of depreciation are combined to yield the resultant rate for the fixed asset is illustrated in figure 1C. During the period from age zero to age 5 years, the three separate rates of depreciation (3, 5, and 1 percent) are added together to obtain a total rate of depreciation of 9 percent per year. For this 5-year period, then, the total depreciation was $5 \times 9 = 45$ percent. From age 5 years to age 13 years two separate rates (5 and 1 percent) are added together to obtain the total rate of depreciation of 6 percent per year. For this 8-year period the total was $8 \times 6 = 48$ percent. In the final period, from age 13 years to age 20 years, the total rate of depreciation for the fixed asset was 1 percent per year. For this 7-year period, the total was $7 \times 1 = 7$ percent. The grand total depreciation for the three periods (45, 48, and 7 percent) is 100 percent of the original amount.

The unit summation method has the merit of relating depreciation charges to the service given by each of the units (depletions) comprising the group. It tends to reduce the underaccrual of depreciation charges on short-lived units and the overaccrual on long-lived units which is common to certain other methods for computing depreciation of group properties.

The example shown in figure 1 illustrates a situation in which all of the original fixed asset has been depleted. Comparable situations usually do not exist on highway control sections since much of the original investment (roadway and drainage grading and earthwork, for example) has not been depleted. For this undepleted capital it is necessary that the remaining life expectancy be estimated. Indications of service life may be obtained from the analysis of construction investment retirements, a phase of the road life studies being conducted by the State highway planning surveys in cooperation with the Bureau of Public Roads.

The share of construction costs which may properly be charged to a control section during a given year is found by adding together the depreciation charges which have been computed for that year for all improvements built within the control section. These figures in turn are made up of actual or estimated depreciation charges for the individual fixed-asset accounts comprising the improvement in accordance with the methods outlined above.

### *Forms for Computations*

Depreciation computations can be greatly facilitated by the use of well-designed forms. A form which provides for all possible adjustments to depreciation rates and for all future additions of data may become unnecessarily complicated. A simpler form will usually prove more desirable even though it may require the occasional preparation of a new depreciation sheet for the control section when an appreciable revision is caused by later reconstruction.

Forms 1 and 2, shown in figure 2, are examples of the type of form used for computing and summarizing depreciation data for control sections and are shown in this report for illustrative purposes only. To facilitate comparing the cost of one section of road with the cost of any other, these particular forms provide for showing depreciation as an annual charge on a per-mile basis for any selected segment within the control section and for the control section as a whole. It will be noted also that these forms provide for adjusting depreciation charges to a common price level in order that all costs may be expressed in terms of dollars having approximately the same purchasing power.

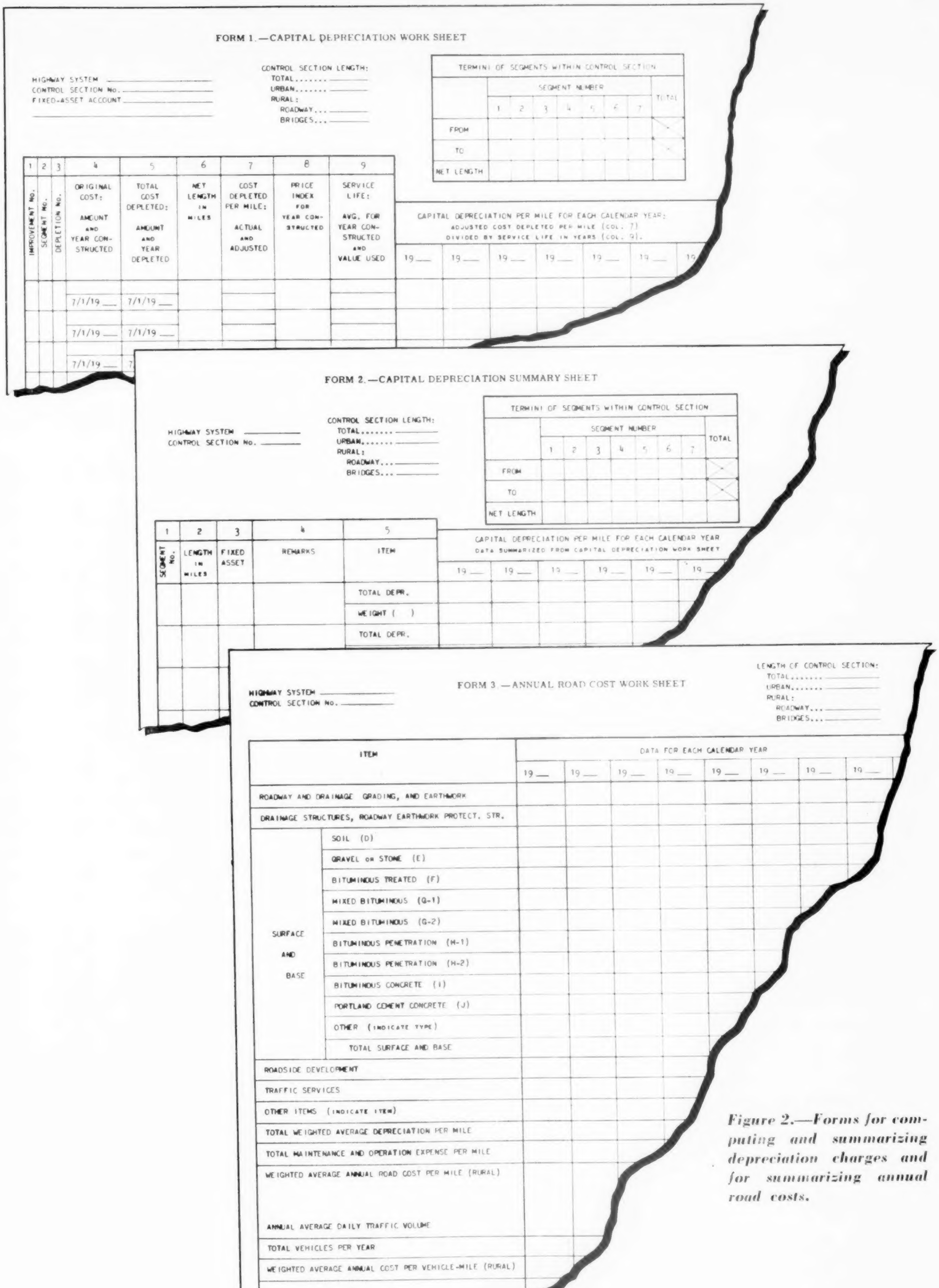
Correlating maintenance and operation expense with depreciation charges can be readily undertaken in those States that have established control sections since this is one of the basic functions of the control section procedure. In the same way that depreciation charges are adjusted to a common price level, maintenance and operation expense is adjusted by means of a maintenance price index to a common price level. The same base periods should be used for both the construction and maintenance price indexes.

Form 3 (fig. 2) is an example of a form for summarizing depreciation charges and maintenance and operation expense on a per-mile basis for a given control section. This particular form is for illustrative purposes only and should be designed in each instance to fit the needs in a given State. For example, bridge data are not recorded on form 3, but may readily be included, if desired.

The annual road cost per mile for the control section is obtained by adding the total annual depreciation charge per mile for the control section and the corresponding maintenance and operation expense per mile.

[5] Methods of developing a progressive record of construction investment are outlined in the Bureau of Public Roads Planning Survey Memorandum No. 322, June 30, 1939: *Further suggestions on the summary and tabulation of the road life studies.*

[6] *Depreciation of Group Properties,* by Robley Winfrey, Iowa Engineering Experiment Station Bulletin 155, 1942; Iowa State College, Ames, Iowa.



FORM 1.—CAPITAL DEPRECIATION WORK SHEET

HIGHWAY SYSTEM ____
CONTROL SECTION No. ____
FIXED-ASSET ACCOUNT ____

CONTROL SECTION LENGTH:
TOTAL....... ____
URBAN....... ____
RURAL:
ROADWAY... ____
BRIDGES... ____

| TERMINI OF SEGMENTS WITHIN CONTROL SECTION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SEGMENT NUMBER | | | | | | | TOTAL |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| FROM | | | | | | | | |
| TO | | | | | | | | |
| NET LENGTH | | | | | | | | |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | CAPITAL DEPRECIATION PER MILE FOR EACH CALENDAR YEAR: ADJUSTED COST DEPLETED PER MILE (COL. 7) DIVIDED BY SERVICE LIFE IN YEARS (COL. 9). | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IMPROVEMENT No. | SEGMENT No. | DEPLETION No. | ORIGINAL COST: AMOUNT AND YEAR CONSTRUCTED | TOTAL COST DEPLETED: AMOUNT AND YEAR DEPLETED | NET LENGTH IN MILES | COST DEPLETED PER MILE: ACTUAL AND ADJUSTED | PRICE INDEX FOR YEAR CONSTRUCTED | SERVICE LIFE: AVG. FOR YEAR CONSTRUCTED AND VALUE USED | 19__ | 19__ | 19__ | 19__ | 19__ | 19__ | 19 |
| | | | 7/1/19__ | 7/1/19__ | | | | | | | | | | | |
| | | | 7/1/19__ | 7/1/19__ | | | | | | | | | | | |
| | | | 7/1/19__ | 7 | | | | | | | | | | | |

FORM 2.—CAPITAL DEPRECIATION SUMMARY SHEET

HIGHWAY SYSTEM ____
CONTROL SECTION No. ____

CONTROL SECTION LENGTH:
TOTAL....... ____
URBAN....... ____
RURAL:
ROADWAY... ____
BRIDGES... ____

| TERMINI OF SEGMENTS WITHIN CONTROL SECTION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SEGMENT NUMBER | | | | | | | TOTAL |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| FROM | | | | | | | | |
| TO | | | | | | | | |
| NET LENGTH | | | | | | | | |

| 1 | 2 | 3 | 4 | 5 | CAPITAL DEPRECIATION PER MILE FOR EACH CALENDAR YEAR DATA SUMMARIZED FROM CAPITAL DEPRECIATION WORK SHEET | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| SEGMENT No. | LENGTH IN MILES | FIXED ASSET | REMARKS | ITEM | 19__ | 19__ | 19__ | 19__ | 19__ | 19__ |
| | | | | TOTAL DEPR. | | | | | | |
| | | | | WEIGHT ( ) | | | | | | |
| | | | | TOTAL DEPR. | | | | | | |

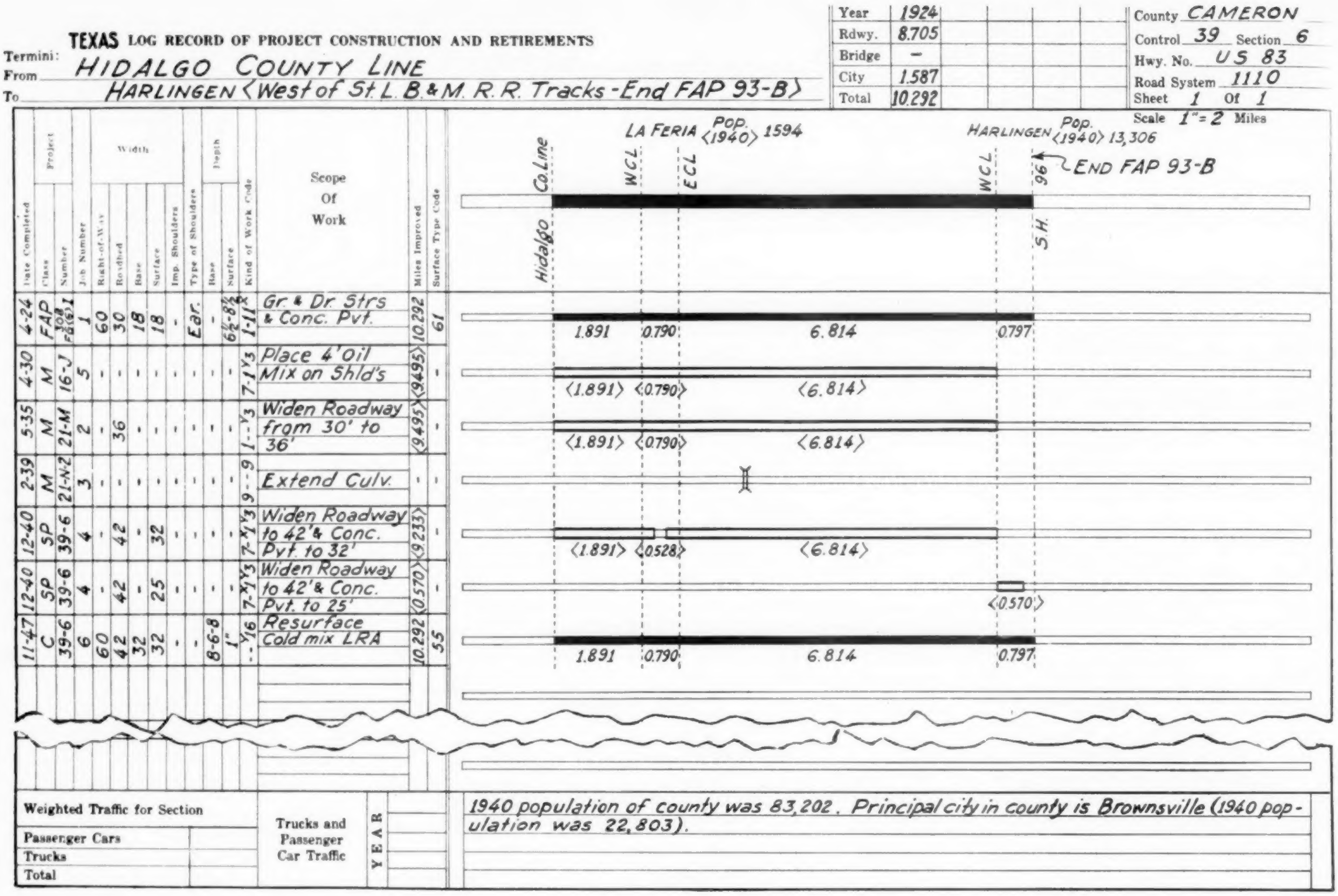
FORM 3.—ANNUAL ROAD COST WORK SHEET

HIGHWAY SYSTEM ____
CONTROL SECTION No. ____

LENGTH OF CONTROL SECTION:
TOTAL....... ____
URBAN....... ____
RURAL:
ROADWAY... ____
BRIDGES... ____

| ITEM | | DATA FOR EACH CALENDAR YEAR | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 19__ | 19__ | 19__ | 19__ | 19__ | 19__ | 19__ | 19__ |
| ROADWAY AND DRAINAGE GRADING, AND EARTHWORK | | | | | | | | | |
| DRAINAGE STRUCTURES, ROADWAY EARTHWORK PROTECT. STR. | | | | | | | | | |
| SURFACE AND BASE | SOIL (D) | | | | | | | | |
| | GRAVEL OR STONE (E) | | | | | | | | |
| | BITUMINOUS TREATED (F) | | | | | | | | |
| | MIXED BITUMINOUS (G-1) | | | | | | | | |
| | MIXED BITUMINOUS (G-2) | | | | | | | | |
| | BITUMINOUS PENETRATION (H-1) | | | | | | | | |
| | BITUMINOUS PENETRATION (H-2) | | | | | | | | |
| | BITUMINOUS CONCRETE (I) | | | | | | | | |
| | PORTLAND CEMENT CONCRETE (J) | | | | | | | | |
| | OTHER (INDICATE TYPE) | | | | | | | | |
| | TOTAL SURFACE AND BASE | | | | | | | | |
| ROADSIDE DEVELOPMENT | | | | | | | | | |
| TRAFFIC SERVICES | | | | | | | | | |
| OTHER ITEMS (INDICATE ITEM) | | | | | | | | | |
| TOTAL WEIGHTED AVERAGE DEPRECIATION PER MILE | | | | | | | | | |
| TOTAL MAINTENANCE AND OPERATION EXPENSE PER MILE | | | | | | | | | |
| WEIGHTED AVERAGE ANNUAL ROAD COST PER MILE (RURAL) | | | | | | | | | |
| ANNUAL AVERAGE DAILY TRAFFIC VOLUME | | | | | | | | | |
| TOTAL VEHICLES PER YEAR | | | | | | | | | |
| WEIGHTED AVERAGE ANNUAL COST PER VEHICLE-MILE (RURAL) | | | | | | | | | |

*Figure 2.—Forms for computing and summarizing depreciation charges and for summarizing annual road costs.*



TEXAS LOG RECORD OF PROJECT CONSTRUCTION AND RETIREMENTS

Termini:
From HIDALGO COUNTY LINE
To HARLINGEN <West of St. L. B.& M. R.R. Tracks - End FAP 93-B>

| | |
|---|---|
| Year | 1924 |
| Rdwy. | 8.705 |
| Bridge | – |
| City | 1.587 |
| Total | 10.292 |

County CAMERON
Control 39 Section 6
Hwy. No. US 83
Road System 1110
Sheet 1 Of 1
Scale 1" = 2 Miles

Hidalgo Co. Line — WCL — LA FERIA Pop. <1940> 1594 — ECL — HARLINGEN Pop. <1940> 13,306 — WCL — S.H. 96 — END FAP 93-B

| Date Completed | Project Class | Project Number | Job Number | Width Right-of-Way | Width Roadbed | Width Base | Width Surface | Imp. Shoulders | Type of Shoulders | Depth Base | Depth Surface | Kind of Work Code | Scope Of Work | Miles Improved | Surface Type Code | Lengths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4-24 | FAP | 308 FA(3) I | 1 | 60 | 30 | 18 | 18 | - | Ear. | - | 6½-8½ | 1-11X | Gr. & Dr. Strs & Conc. Pvt. | 10.292 | 61 | 1.891, 0.790, 6.814, 0.797 |
| 4-30 | M | 16-J | 5 | - | - | - | - | - | - | - | - | 7-1⅓ | Place 4' Oil Mix on Shld's | <9.495> | - | <1.891> <0.790> <6.814> |
| 5-35 | M | 21-M | 2 | - | 36 | - | - | - | - | - | - | 1--⅓ | Widen Roadway from 30' to 36' | <9.495> | - | <1.891> <0.790> <6.814> |
| 2-39 | M | 21-N-2 | 3 | - | - | - | - | - | - | - | - | 9--9 | Extend Culv. | - | - | |
| 12-40 | SP | 39-6 | 4 | - | 42 | - | 32 | - | - | - | - | 7-X1⅓ | Widen Roadway to 42' & Conc. Pvt. to 32' | <9.233> | - | <1.891> <0.528> <6.814> |
| 12-40 | SP | 39-6 | 4 | - | 42 | - | 25 | - | - | - | - | 7-X1⅓ | Widen Roadway to 42' & Conc. Pvt. to 25' | <0.570> | - | <0.570> |
| 11-47 | C | 39-6 | 6 | 60 | 42 | 32 | 32 | - | - | 8-6-8 | 1" | --1/16 | Resurface Cold mix LRA | 10.292 | 55 | 1.891, 0.790, 6.814, 0.797 |

| Weighted Traffic for Section | |
|---|---|
| Passenger Cars | |
| Trucks | |
| Total | |

Trucks and Passenger Car Traffic — YEAR

1940 population of county was 83,202. Principal city in county is Brownsville (1940 population was 22,803).

*Figure 3.—Log record of project construction and retirements for Texas control section 39-6.*

At the bottom of form 3, space should be provided for special computations. One such possible computation is the cost per vehicle-mile, as shown on the form. Others may be entered on the form at the discretion of the highway department to show trends in the annual costs of the control section in relation to other factors.

### Annual Road Cost Data

As an example of annual cost determinations, a highway in Texas is here considered. Figure 3 shows one of the construction project log records prepared by the Texas State Highway Department for control section 39-6 on a portion of U S 83 in Cameron County, the southernmost county in the State. This control section begins at the west county line and extends eastward to the intersection with State Route 96 in the city of Harlingen. The total length of the control section is 10.292 miles, but only the rural portion of 8.705 miles is embraced in the following discussion.

A view of the roadway looking to the west from just inside the city limits of Harlingen is shown in figure 4, and another part of the control section is depicted on the cover. The existing three-lane surface is 32 feet wide and consists of a 1-inch limestone rock-asphalt mat on an old portland cement concrete base.

Although agriculture plays a dominant role in the economy of the county, one-half of the population lives in urban areas. Interurban bus service is scheduled at frequent intervals along this route. There are a number of manufacturing establishments in the county, some of which depend on local crops for raw materials. Many of these establishments rely upon motor carriers to support their operations. The area also has a modest tourist trade. Average traffic on control section 39-6 was 3,389 vehicles per day in 1936. Following a wartime decline


*Figure 4.—View of the eastern end of Texas control section 39-6.*

to 2,659 in 1943, the average traffic increased to 5,542 vehicles per day in 1948.

Annual roadway costs for an average mile of control section 39–6 are shown in the upper left portion of figure 5. In this illustration all costs have been adjusted to a 1937–41 price level. Bridge costs were omitted from the computations of costs, but could be included, if desired, with no change in the general procedure.

The annual depreciation charges, as obtained from the investment study, extend back to 1924. Data on maintenance and operation expense, however, date back only to 1936. The State's control-section setup was not in full operation before that date, and maintenance and operation expense could not be correlated with construction costs for the years prior to 1936. Consequently, the data presented in figure 5 begin with the year 1936.

Only the total annual depreciation and the total maintenance and operation expense are shown in figure 5. Similar charts could be prepared for each of the fixed-asset accounts, if desired, by selecting the appropriate data from the annual road cost work sheet for the control section.

For purposes of general illustration, annual average daily traffic information has been obtained for control section 39–6, and an annual cost per vehicle-mile computed. These data are also shown in the left side of figure 5. The true significance of such a trend for a particular control section can, of course, be properly appraised only after consideration and study of many factors, such as composition and type of traffic, frequency of heavy axle loads, subgrade conditions, degree of maintenance afforded, and type and width of surface and shoulders.

### *Cost Trends*

In order to smooth out the somewhat erratic trends characteristic of these data when presented on an annual basis, averages for a group of years may prove more useful. The right side of figure 5 shows the annual cost data for control section 39–6 on the basis of 5-year averages. In this case the 5-year averages are plotted at the last year of each 5-year group. Thus, the average for 1936–40 is plotted at 1940, and so on. The trends are more apparent when the data are arranged this way, thus making them more acceptable for general administrative use. The average annual daily traffic and annual cost per vehicle-mile, on a 5-year average basis, are also shown in the right side of figure 5.

Computations similar to the foregoing have been made for other control sections in Texas and other States. The annual cost per mile, traffic volume, and annual cost per vehicle-mile for four additional control sections in Texas are shown in the upper

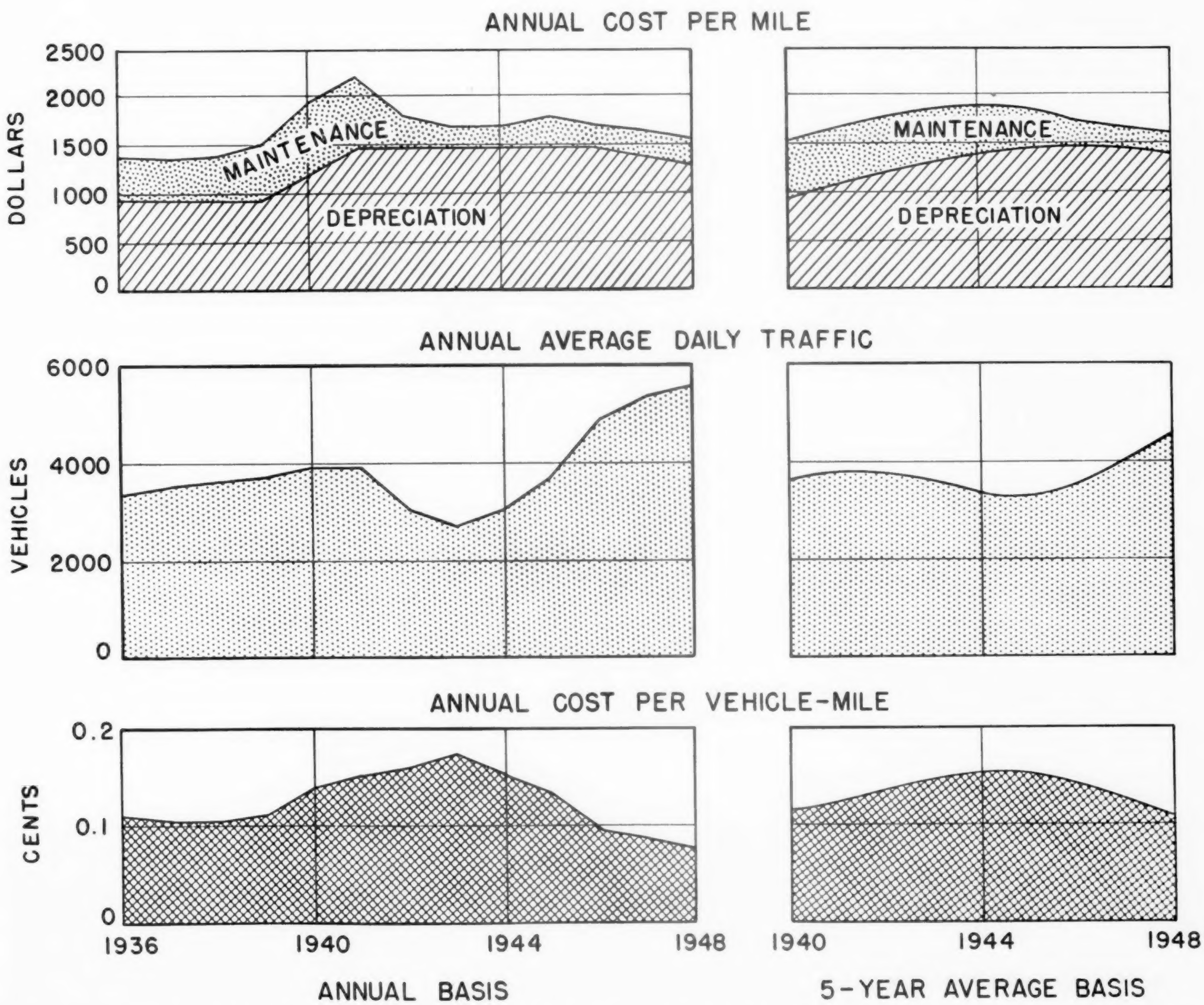



*Figure 5.—Annual cost per mile, annual average daily traffic, and annual cost per vehicle-mile, on an annual basis and a 5-year average basis, for Texas control section 39-6 (data adjusted to 1937–41 prices).*

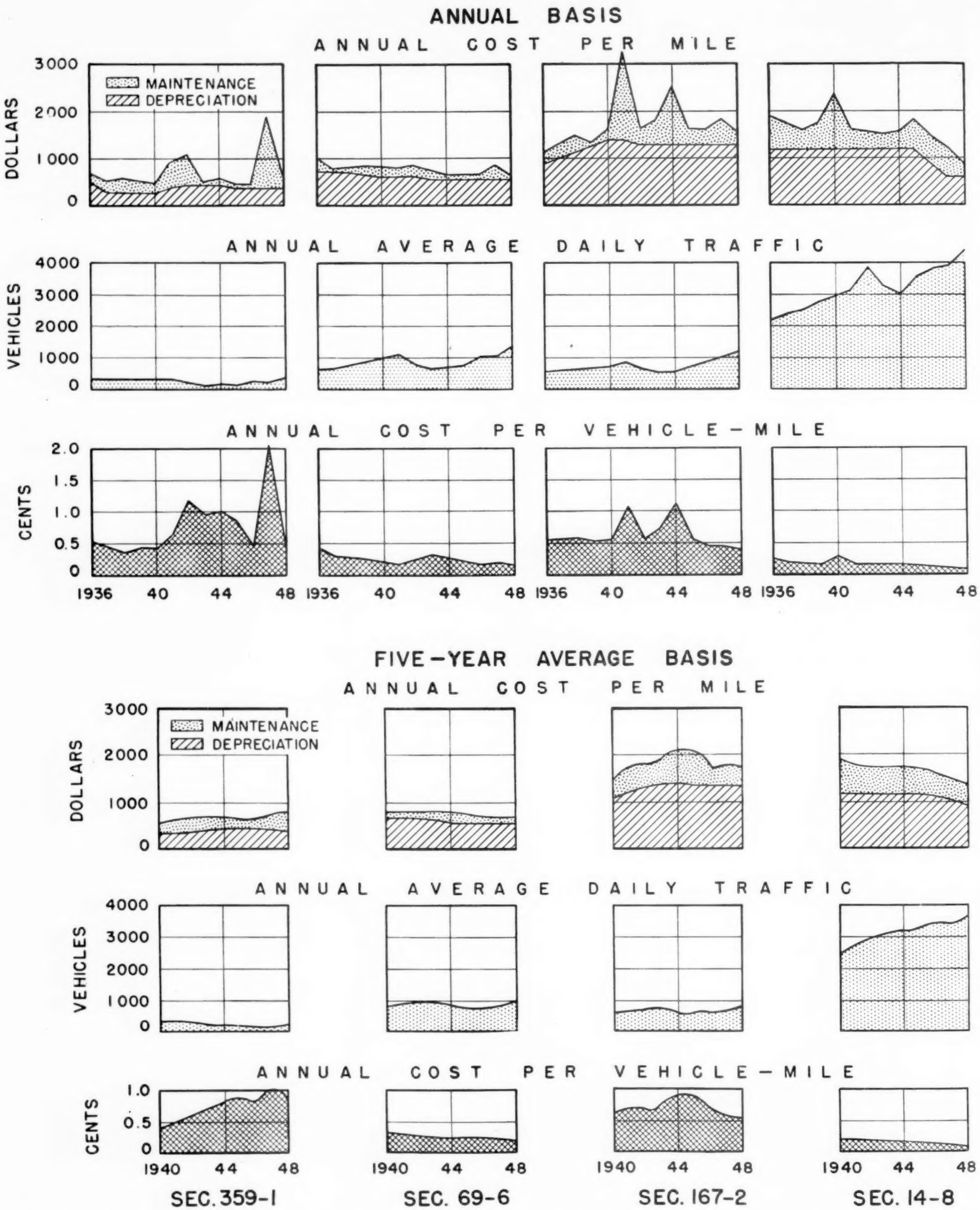



*Figure 6.—Annual cost per mile, annual average daily traffic, and annual cost per vehicle-mile, on an annual basis and a 5-year-average basis, for four Texas control sections (data adjusted to 1937–41 prices).*

part of figure 6. Similarly, the 5-year-average annual cost per mile, 5-year-average daily traffic, and 5-year-average annual cost per vehicle-mile for the same sections are shown in the lower part of figure 6. These control sections, which were selected at random, are briefly described in table 1. The cost data shown here are not necessarily representative of the average cost of these road types and consequently conclusions should not be drawn from this small sample as to relative cost.

**Table 1.—*Length, type, and location of control sections***

| Control section number | Length | Number of lanes | Surface type | Route | County | Location |
|---|---|---|---|---|---|---|
| | *Miles* | | | | | |
| 359-1 | 7.102 | 2 | Bituminous surface treated. | Texas 119 | DeWitt | From Yorktown southeast toward Goliad. |
| 69-6 | 9.768 | 2 | Bituminous penetration. | U S 87 | Tom Green | From Coke County line southeast toward San Angelo. |
| 167-2 | 15.246 | [1] 2 | Bituminous concrete | U S 54 | El Paso | From El Paso north to New Mexico State line. |
| 14-8 | 10.062 | [2] 2 | Portland cement concrete. | U S 77 and 81 | McLennan | From Hill County line south toward Waco. |

[1] 4.776 miles adjacent to El Paso were widened to four lanes in 1941.
[2] 0.544 mile at the south end was built (1934) as three lanes.

# New Publications

## THE MATHEMATICAL THEORY OF VIBRATION IN SUSPENSION BRIDGES

The Bureau of Public Roads has recently published *The Mathematical Theory of Vibration in Suspension Bridges*, a 450-page report of a study undertaken under the auspices of the Advisory Board on the Investigation of Suspension Bridges. The book is for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at $1.25 a copy.

The Advisory Board, established subsequent to the collapse of the Tacoma Narrows Bridge in 1940, has sponsored a series of investigations seeking to determine the causes of suspension bridge vibration, to develop a rational theory explanatory of the phenomenon, and to work out methods of design practice which will reduce these dangerous motions.

*The Mathematical Theory of Vibration in Suspension Bridges* develops mathematical analyses of the dynamic problem and suggests experimental data needed to support them. Authors of this highly technical study are Dr. Friedrich Bleich, Consulting Engineer, American Institute of Steel Construction; Dr. C. B. McCullough, Assistant Chief Engineer, Oregon State Highway Commission; Richard Rosecrans, Structural Research Engineer, Oregon State Highway Commission; and George S. Vincent, Principal Highway Bridge Engineer, Bureau of Public Roads. Unfortunately, both Dr. Bleich and Dr. McCullough died before their work appeared in published form.

The content of the publication is indicated by the subjects of the major sections:

Chapter 1.—History of troublesome dynamic stress effects in suspension bridges; a general statement of the dynamic problems; the mathematical theory of vibration problems.

Chapter 2.—A general statement of the problem and determination of physical data needed for its solution.

Chapter 3.—Frequencies, modes of vibration, and energy storage in freely vibrating suspension bridges with hinged stiffening frames.

Chapter 4.—Application of the energy method to the analysis of the frequencies, modes of vibration, and energy storage capacity in freely vibrating suspension bridges with continuous stiffening frames.

Chapter 5.—Influence of various design factors on frequencies, modes of motion, and energy storage.

Chapter 6.—Consideration of structural damping in suspension bridges.

Chapter 7.—The flutter theory of truss-stiffened suspension bridges under wind action.

Chapter 8.—The linearized deflection theory developed for suspension bridges having tower stays.

Chapter 9.—Experimental verification of the linearized deflection theory.

## SELECTED BIBLIOGRAPHY ON HIGHWAY FINANCE

The Bureau of Public Roads has recently published a *Selected Bibliography on Highway Finance* which provides nearly 1,400 annotated references, for the years 1939–49, in the field of highway taxation and finance in the United States. Emphasis is placed chiefly on theory, but basic sources of pertinent statistics are included. The bibliography may be purchased from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at [illegible]5 cents a copy.

The search for solutions to the problems currently encountered by all levels of government in obtaining adequate revenues for highway operation and capital outlay has intensified the value of all types of information on finance. The *Selected Bibliography on Highway Finance* is the complete key to this need.

The references in the bibliography are arranged according to a useful classification scheme under seven major topics—general discussions, taxation, expenditures, borrowing, financial programs and plans, miscellaneous topics, and statistics. Both geographical and author indexes are included in the publication.

Brief annotations accompany most entries to indicate the general nature of content, but evaluation of importance, accuracy, or validity has not been attempted. The references were carefully selected, however, so that all included are of some significance.

While the bibliography covers intensively the years 1939–49, a limited number of significant references from earlier years are also included, as are available items published in the first four months of 1950.

## HIGHWAY STATISTICS, 1949

Now available is the Bureau of Public Roads' *Highway Statistics, 1949*, the fifth of the bulletin series presenting annual statistical and analytical tables of general interest on the subjects of motor fuel, motor vehicles, highway-user taxation, financing of State highways, and highway mileage. Included for the first time in the annual publication is information concerning the financing of highways by county and local rural governments.

*Highway Statistics, 1949* is for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 55 cents a copy. The full series of the annual bulletins are available from the Superintendent of Documents, as indicated on the inside back cover of PUBLIC ROADS.

# Methods for the Determination of Soft Pieces in Aggregate

*BY THE PHYSICAL RESEARCH BRANCH*
*BUREAU OF PUBLIC ROADS*

**Reported by D. O. WOOLF, Senior Materials Engineer**

*Figure 1.—Toughness test for gravel, using the 2½-inch ball.*

***The classification of materials in aggregates as "soft pieces" is subject to wide variation and loose definition. Materials classed as soft pieces in various State specifications also include those which more properly should be defined as unsound, light-weight, brittle, friable, highly absorbent, or combinations of these. As pointed out in this article, specifications for aggregates should define and limit soft pieces as such, and the presence of other deleterious substances should be separately restricted.***

***The study reported here included an examination of existing methods, and an attempt to develop new ones, for the determination of the presence and proportion of soft pieces in aggregate. All commonly known test methods, and many specially devised ones, were studied. It was concluded that the only method suitable for both field and laboratory use is the scratch hardness test using a hard, yellow brass scribe. For convenience, a wooden pencil with a brass core is suggested.***

IN 1941 the Bureau of Public Roads undertook an investigation of methods of testing coarse aggregates to determine the content of soft pieces, at the request of Subcommittee IX of Committee C-9 of the American Society for Testing Materials. It was hoped that the results of this investigation would direct attention toward the development of a new method of testing aggregates for soft pieces, or identify existing methods which would be suitable for this purpose.

This paper describes the test methods employed and gives typical test values which were obtained. With each description of a method of test are presented the conclusions obtained from the test data: Whether the method appears to be useful, and the difficulties encountered in its performance. Throughout the investigation, efforts were made to develop a method which would be suitable for use in the field. It is thought that this determination—the detection of the amount of soft pieces in aggregates—is properly a duty of the inspector in the field. Any method which the inspector can use can also be performed in the laboratory; consequently, the program of the investigation was planned with consideration of field use as a primary requisite. In some of the methods employed, apparatus suitable only for use in the laboratory was used. In most of these cases, however, plans were prepared for the construction of equipment sufficiently portable to permit its installation at aggregate plants.

### *Conclusions*

The tests reported were made in an attempt to develop a rational method of testing aggregates for soft-piece content. Although most tests used standard or readily procurable apparatus, some rather fanciful or weird contraptions were designed or actually constructed for this purpose. On the whole, a thorough study has been made of all different methods of test which could be expected to give information of value.

Of all methods tried, the only one considered suitable for both laboratory and field use is the scratch hardness test using a hard, yellow brass scribe. For convenience, a pencil with a brass core is suggested.

Attention is called to the rather frequent practice, in writing specifications for aggregates, of using the soft-piece classification as a catch-all for many different types of deleterious substances. If it is desired to limit types of deleterious substances other than soft pieces, these other types should be mentioned specifically and separately, in the specifications, from pieces which are merely soft.

### *Classification of Materials*

Prior to starting this investigation of methods of test, an attempt was made to determine the character of the materials which the various highway authorities classify as soft pieces. The State highway departments were requested to submit samples of such soft pieces as are encountered in each State, and to furnish information relating to their particular conditions insofar as this problem is concerned. The information requested was as follows:

1. Names of the different materials which may be classified as soft pieces.
2. Names of such materials found generally throughout the State or in large areas of the State.
3. Amount of soft pieces permitted in specifications for pavement surface courses.
4. Method of test or identification used by laboratory operators or field inspectors.
5. Names of the materials occurring naturally which are considered to be objectionable for surface courses but which are not included in the class of soft pieces.

Replies were received from practically all of the State highway departments. Many were in sufficient detail, but a few were expressed in generalities, or in terms which appear to be of local usage only. From the information received, table 1 reports a list of materials which are classed as "soft pieces," the number of States which classify these materials as soft, and the number of States which report the materials to be widely distributed.

At first glance, many of the materials listed in table 1 appear to be included in the designation of soft pieces by mistake.

For example, granite is placed in the classification of soft pieces by two States, although the word "granite" usually conveys the impression of a hard and enduring stone. A number of other apparent inconsistencies exists. However, some interpretation of these classifications is probably permissible.

There is little doubt that the inclusion of granite in a classification of soft pieces is meant to refer to material of a granitic nature which has weathered to such an extent that the component crystals are soft or poorly bonded to each other. Similar interpretations can be made of a number of the materials included in table 1 and, in general, most of the materials mentioned can be placed in one or more of the following types:

1. Soft.
2. Unsound.
3. Light weight.
4. Brittle.
5. Friable.
6. Highly absorbent.

Some materials may be both soft and friable, or soft and brittle, or different samples of the same material may be placed properly in separate groups. Consequently, without reference to actual samples, a proper grouping of materials by name alone is probably not feasible. Certain materials mentioned in table 1, such as brownstone, micaceous granite, and limonite, are not identified definitely by the names given, although use of such terms may be justified in a limited area where the persons concerned would have an understanding of their application. However, as these terms may not be widely used to describe materials of definite physical characteristics, some thought could be given toward the use of more descriptive names, or to the establishment and use of a systematized glossary of terms relating to the materials under consideration.

Materials classed as deleterious but not considered as soft pieces by the reporting authority are listed below:

| | |
|---|---|
| Alkaline reactive | Mica |
| Amphibolite | Mud balls |
| Chert | Obsidian |
| Chert, opaline | Ochre |
| Chert, unsound | Pyrite in rock |
| Clay lumps | Quartzite |
| Coal | Sandstone, hard absorbent |
| Coated material | Sandstone, soft |
| Dolomite, some | Shale |
| Flint | Shale, hard |
| Glassy rock | Shale, opaline cherty |
| Gneiss, soft | Shale, soft |
| Granite | Shale, some |
| Granite, soft | Shell |
| Granite, some | Slate |
| Gravel, a quartz | Sulphates–sulphides, iron, in rock |
| Hydrophilic rock | Thin or elongated pieces |
| Limestone, argillaceous | Unsound pieces |
| Limestone, siliceous | |

**Table 1.**—*List of materials classed as soft pieces and number of States giving this classification or having material widely distributed*

| Material | Number of States— | | Material | Number of States— | |
|---|---|---|---|---|---|
| | Classifying as soft | Reporting wide distribution | | Classifying as soft | Reporting wide distribution |
| Basalt, disintegrated | 1 | 1 | Limestone, soft | 3 | 1 |
| Brownstone | 1 | 1 | Limestone, some varieties | 1 | 1 |
| Caliche, hard | 1 | 0 | Limestone, weathered | 4 | 3 |
| Chert | 2 | 1 | Limonite | 3 | 2 |
| Chert, chalky | 1 | 0 | Marble | 1 | 1 |
| Clay balls | 2 | 1 | Ochre | 3 | 2 |
| Clay, iron bearing | 1 | 0 | Quartz, sugar | 1 | 1 |
| Coal | 2 | 1 | Quartz, weathered | 2 | 2 |
| Concretion, calcareous | 1 | 1 | Rock, disintegrated | 2 | 1 |
| Conglomerate | 1 | 0 | Rock, weathered | 2 | 2 |
| Dolomite, weathered and porous | 1 | 1 | Rottenstone | 1 | 1 |
| Earth, diatomaceous | 1 | 1 | Sandstone | 9 | 9 |
| Feldspar | 1 | 1 | Sandstone, argillaceous | 1 | 1 |
| Felsite | 1 | 0 | Sandstone, friable | 1 | 1 |
| Floaters | 1 | 1 | Sandstone, friable arkosic | 1 | 0 |
| Gneiss | 1 | 0 | Sandstone, soft | 5 | 4 |
| Gneiss, micaceous | 1 | 1 | Schist | 5 | 3 |
| Gneiss, weathered | 1 | 1 | Schist, some | 1 | 1 |
| Granite | 2 | 1 | Schist, micaceous | 1 | 0 |
| Granite, decomposed | 1 | 1 | Schist, talc | 1 | 0 |
| Granite, disintegrated | 4 | 3 | Schist, weathered | 2 | 2 |
| Granite, micaceous | 1 | 1 | Scoria | 1 | 1 |
| Granite, weathered | 3 | 3 | Scoria, certain grades of | 1 | 1 |
| Gravel, cemented | 2 | 1 | Shale | 11 | 7 |
| Gravel, magnesia | 1 | 1 | Shale, clay | 1 | 1 |
| Iron clay balls | 1 | 1 | Shale, diatomaceous | 1 | 1 |
| Iron oxide | 2 | 1 | Shale, disintegrated | 1 | 1 |
| Limestone, argillaceous | 2 | 1 | Shell | 2 | 1 |
| Limestone, porous | 1 | 1 | Soapstone | 1 | 0 |
| Limestone, shelly | 1 | 0 | Volcanic rock, coarse | 1 | 1 |

It is interesting to note, in this list of 37 items, that 17 are placed in the category of soft pieces by other States. This illustrates one of the difficulties encountered in attempting to coordinate requirements or tests for soft pieces in aggregate. Unless there can be some agreement as to what constitutes a soft piece, work along the proposed line may not be of suitable value.

Table 2 presents a compilation of the various State specifications for limitation of soft pieces. Most specifications limit the content of soft pieces of aggregate to 5 percent or less. In a few cases, limits for specific types of soft particles are given, but usually the specifications fail to identify the materials covered by the requirement.

## *Test Methods Reported by States*

The following methods of test to determine the content of soft pieces of aggregate were reported by the States:

| | *Number of States* |
|---|---|
| Los Angeles abrasion test | 10 |
| Breakage test under roller | 1 |
| Visual inspection | 14 |
| Scratch test | 4 |
| Hand hammer or compression test | 4 |
| Douglass stone meter | 2 |
| Specific gravity | 2 |
| Solubility in acid | 1 |
| Sulfate soundness test | 2 |
| Absorption test | 1 |
| Flotation by heavy liquid | 1 |
| Gravel impact test | 1 |
| Deval abrasion test | 1 |

The methods most commonly used are visual inspection, the Los Angeles abrasion test, the scratch test, and a test by use of a hand hammer or compression machine. These and the other tests listed are of two types—a test in which the individual particles are examined separately, and a test in which the effect of soft pieces on a characteristic of the entire material is determined. It should be noted that, with the exception of the requirement involving the use of the sodium-sulfate test, all of the specification requirements shown in table 2 necessitate the use of the first type of test and, in the one exception, this type of test is used in part. Consequently, there appears to be a strong opinion to the effect that determinations of the content of soft pieces should be based on actual count or weight of particles rather than through the use of an indirect method involving some characteristic pertaining to the whole sample.

A number of the States report the use of certain methods of test—the Los Angeles abrasion test for example—for determining

**Table 2.**—*State specification limitations for soft pieces*

| Item | Specification limit | Number of State specifications |
|---|---|---|
| | *Percent* | |
| Soft pieces | 2 | 2 |
| Do | 3 | 3 |
| Do | 5 | 4 |
| Do | 10 | 1 |
| Do | Free from excess. | 1 |
| Soft pieces, bituminous aggregate | 1 | 2 |
| Soft pieces, concrete aggregate | 2 | 2 |
| Do | 3 | 1 |
| Soft pieces: Concrete aggregate | 6 | 1 |
| Soft pieces: Cover material | 7 | |
| Soft pieces: Oil mix material | 12 | |
| Soft pieces: Stabilized material | 20 | |
| Clay lumps | 0.5 | 1 |
| Shale | 2.0 | |
| Sp. gr. less than 1.95 | 2.0 | |
| Total shale, coal, clay lumps, and soft fragments | 5 | 1 |
| If loss in $Na_2SO_4$ test is less than 2 percent, soft shale may not exceed | 10 | 1 |
| If loss is 2.0 percent or greater, soft shale is limited to | 6 | |

the presence of soft pieces in aggregate, but fail to include numerical values in their reported limitation requirements for soft pieces which are applicable to these methods. Although the reporting authorities may consider the methods mentioned to be suitable for use, it is probable that lack of sufficient test data has so far prevented the establishment of specification requirements.

Eighty-four samples of aggregates were submitted by the States in response to the request for typical samples of material composed of soft pieces. In a number of cases the samples were confined, as requested, to a given type of material. However, many samples were found to be composed of a number of kinds of material differing as greatly as limestone and gneiss. It is possible that the request for samples composed wholly of soft pieces was misunderstood, and that some samples were submitted which contained a small amount of soft pieces as it naturally occurred in these materials.

From the number of varieties of materials submitted as representing soft pieces, it is apparent that there is no concordance of opinion as to the kind of material which should be thus described. It is further apparent that the term "soft pieces" is used as a catch-all description of a number of different types of possibly undesirable material in aggregates. Prior to spending much time in testing materials, it was realized that some rational conception must be formed of the type of material to be identified by the test procedure. Choice must be made between the application of the term "soft pieces" to pieces of aggregate which are actually soft, or the application of the same term to pieces of a wide variety of characteristics. Although the latter may be undesirable for use in construction, this is their only common feature. As shown in the samples submitted, these pieces may be hard or soft, tough or brittle, sound or unsound; in fact, they include the whole gamut of physical properties of aggregates. To this question of choice, there can be but one answer: If these tests are to identify soft pieces, the only problem to be considered is whether the piece under test is hard or soft. During the course of this investigation, tests foreign to a strict hard-or-soft determination were made. In these tests it was hoped that some correlation between the hardness of the particle and some other characteristic of interest could be established. As a general rule, the results were rather disappointing. Although in some cases, with selected samples, definite correlations were found between the hardness and some other characteristic of a material, when a wider variety of samples was considered the agreement between the two characteristics appeared to be largely a matter of chance.

## Classification of Test Methods

The tests made in this investigation may be grouped in the following classifications:

1. Visual inspection.
2. Scratch hardness.
3. Specific gravity and absorption.
4. Resistance to impact.
5. Resistance to abrasion.
6. Resistance to static loads.
7. Soundness.

In some cases, the tests were made on the material as received; that is, without preliminary separation into individual sizes. In most tests, however, the size of the piece affected the test result to a marked extent, and it was necessary to sieve the test sample into separate sizes. The sizes generally used were 2- to 1½-inch, 1½- to 1-inch, 1- to ¾-inch, and ¾- to ½-inch. Pieces smaller than ½-inch were found to be difficult to test by some methods, and it was thought that it would be sufficient, for the present at least, to study methods of testing the larger pieces only.

In the first series of tests made on the 84 samples submitted by the State highway departments, the samples were separated into three groups with respect to hardness of the material: Soft, hard, and borderline. This was done by a combination of visual inspection and the use of a scratch test employing a steel knife. It was realized that these methods are not dependable for separating any and all materials into hard and soft classifications. However, they can be used to separate unquestionably soft material from unquestionably hard material. The materials that were found to be neither hard nor soft were classified as borderline materials and excluded from further tests.

Visual inspection of aggregates for the presence of soft pieces is associated with what might be called the luster or appearance by reflected light, and the degree of bonding. Pieces of aggregate with a glassy or stony luster are usually classed as hard; those with a dull or earthy appearance are classed as soft. Compact materials are usually placed in the hard classification, while those which have a loose or friable texture are considered as soft.

## Specific Gravity and Absorption

Tests for bulk specific gravity were made on saturated and surface-dry samples using the mason jar pycnometer.[1] This determination does not appear to have any significance in differentiating between hard and soft pieces. Seven samples of hard materials had bulk specific gravities varying from 1.62 to 2.55; five samples of soft materials varied from 1.48 to 2.57; eight samples classed as borderline materials varied from 2.11 to 2.59. Since there is so much overlapping, use of the test for specific gravity to identify hard and soft pieces does not appear feasible.

The absorption test was made by immersing oven-dried samples in water for a period of 24 hours. The samples were then surface-dried with a towel and weighed, and the absorption expressed as a percentage of the dry weight. A summary of the results obtained is given in table 3. In this table, as in others to follow, each size of each material tested is treated as an individual sample. This permits comparisons between the two types of material, hard and soft, for each size of piece. Although the average values for the two types of material differ markedly, there is some overlapping in the test values. In the 1- to ¾-inch size, for example, one sample of soft material had an absorption of only 3.2 percent, whereas a sample of hard material had a quite high absorption of 11.3 percent. Because of this overlapping, it is not possible to set a value separating hard from soft material and this method is of little use for the identification of soft particles.

## Impact Tests

A number of different types of impact tests were used in this investigation. The one which is believed to have the most promise is the test for the toughness of gravel.[2] As shown in figure 1, the apparatus used in this test consists essentially of a 2½-inch steel ball mounted on a steel block to serve as an anvil, and another steel ball of the same size which can be lifted to a maximum height of 7 inches and allowed to fall on the specimen under test. During the course of this investigation, certain improvements in the original apparatus were made so that the ball could be dropped the exact distance desired with but one measurement of the thickness of the specimen under test.

**Table 3.—*Use of the absorption test for the identification of hard and soft materials***

| Item | Size of pieces | | | |
|---|---|---|---|---|
| | 2- to 1½-inch | 1½- to 1-inch | 1- to ¾-inch | ¾- to ½-inch |
| SOFT MATERIAL: | | | | |
| Number of samples | 4 | 30 | 31 | 20 |
| Absorption: | | | | |
| Minimum ... percent | 2.6 | 2.6 | 3.2 | 4.3 |
| Maximum ... do | 23.4 | 30.1 | 29.0 | 30.9 |
| Average ... do | 11.5 | 12.8 | 14.4 | 18.2 |
| HARD MATERIAL: | | | | |
| Number of samples | 6 | 22 | 22 | 10 |
| Absorption: | | | | |
| Minimum ... percent | 1.4 | 0.5 | 0.6 | 1.0 |
| Maximum ... do | 11.1 | 11.3 | 11.3 | 11.0 |
| Average ... do | 4.7 | 2.7 | 3.0 | 3.3 |

[1] Described in *Principles of Highway Construction as Applied to Airports, Flight Strips, and other Landing Areas for Aircraft*, Bureau of Public Roads, June 1943, p. 297.

[2] Method T-6-27, *Standard Specifications for Highway Materials and Methods of Sampling and Testing, 1938;* American Association of State Highway Officials, p. 152. This method has been withdrawn by the Association.

In making this test, the specimen was held on the anvil in its most stable position, usually with the least dimension vertical, and the movable ball dropped on the specimen from a height of 1 inch. The height of fall was increased 1 inch after each blow until the specimen failed or until it withstood a drop of 7 inches. Under normal conditions, a test sample containing 50 to 100 pieces of the same sieve size was used. An empirical value for each sample was obtained by multiplying the number of pieces which failed by the square of the drop, in inches, at which they failed, and dividing the sum of these values by the total number of pieces tested. For the purpose of this computation, pieces which did not fail at a drop of 7 inches were assumed to fail at a drop of 10 inches. This value, called the toughness factor, can vary from a minimum of 1 to a maximum of 100.

The results of these tests are shown in table 4. Although higher toughness factors were found for the hard materials than the soft, there is a considerable amount of overlapping of the two sets of values. It is apparent that the toughness test for gravel does not separate hard from soft material. After a review of the detailed records of this test, it appears that the falling ball is much too heavy to separate soft pieces from hard but brittle pieces. Furthermore, when the brittle piece fails, the fracture is apparent, but many pieces of soft material may fail without the break being seen from above as the operator would normally view the specimen. This results in the soft piece being given a higher rating than it should have, thereby decreasing the value of the test.

In an attempt to correct these difficulties, another toughness apparatus was made using a steel ball of 1⅞-inch diameter. For certain sizes of particles, the 1⅞-inch ball was found to furnish more indicative test results than the 2½-inch ball, but the conclusion was reached that to test aggregate of a complete range in size from 2- or 2½-inch to ⅜-inch, at least three toughness testers of different sizes should be used, and each size used to test material of a definite and narrow range in sieve sizes. As time to develop these testers and correlate the test results of each was not available, further consideration of the use of this type of apparatus was deferred.

Figure 2.—*The rotary soft-stone machine.*

**Table 4.**—*Use of the toughness test (2½-inch ball) for the identification of hard and soft materials*

| Item | Size of pieces | | | |
|---|---|---|---|---|
| | 2- to 1½-inch | 1½- to 1-inch | 1- to ¾-inch | ¾- to ½-inch |
| **Soft Material** | | | | |
| Number of samples | 3 | 28 | 29 | 20 |
| Toughness factor: | | | | |
| Minimum | 18.0 | 2.7 | 2.0 | 1.0 |
| Maximum | 59.0 | 46.2 | 16.9 | 5.7 |
| Average | 41.6 | 20.5 | 7.9 | 2.5 |
| **Hard Material** | | | | |
| Number of samples | 7 | 23 | 23 | 10 |
| Toughness factor: | | | | |
| Minimum | 5.0 | 4.5 | 2.9 | 1.1 |
| Maximum | 79.0 | 67.2 | 32.3 | 10.3 |
| Average | 42.3 | 29.8 | 11.4 | 3.8 |

## *Rotary Soft Stone Machine*

Another type of impact test tried involves the use of the rotary soft stone machine shown in figure 2. This machine consists essentially of a cast-iron disk revolving in a horizontal plane inside a vertical steel drum made of ⅜-inch steel plate. The disk is 29 inches in diameter and the drum has an inside diameter of 33¼ inches. Ribs on the upper surface of the disk form pockets to catch the material fed on the disk through a sheet-metal cone, and to throw these pieces against the steel drum. Another cone below the disk serves to collect the sample and lead it to a pan in which the tested material can be inspected. The disk is powered by a variable-speed motor and can be operated at speeds from 110 to 200 r.p.m. In these tests, the fastest speed was used. The test was conducted on individual sizes of aggregate. The weight of the test sample was determined, and the pieces passed singly through the machine. After all pieces had been tested, the sample was sieved on the original retaining sieve, and the weight of material passing this sieve expressed as a percentage of the original weight of the sample.

The results obtained with the rotary machine are given in table 5. These results indicate the same conditions as were found for the falling-ball apparatus. Hard but brittle material as well as soft material is readily broken in the rotary machine, and it does not appear possible to separate truly soft pieces from others with this type of test.

## *Hand-Hammer Tests*

Several other types of impact tests were tried. In former years, a hammer test was occasionally used to identify soft pieces. Although the application of a hand hammer involves a number of intangible conditions, it was believed desirable to include this test in the investigation. The hammers used varied from a 2-ounce tile-setter's hammer to a stone-mason's hammer with a 2-pound head, as shown in figure 3. Several different types of technique were used. In one, the hammer was allowed to drop without bending of the wrist; in another, the hammer was swung by movement of the wrist only; in a third, the end of the hammer handle was placed on the table and the hammer head allowed to fall through an arc of about 8 inches. The tile-setter's hammer has one flat and one sharply beveled end. With this hammer, one method included a free swing of the arm, with the flat face striking the piece under test. In another application of the same small hammer, the beveled end was used to peck at the test specimen to determine whether or not the material could be flecked away or cut by

**Table 5.**—*Use of the rotary soft-stone machine for the identification of hard and soft materials*

| Item | Size of pieces | | | |
|---|---|---|---|---|
| | 2- to 1½-inch | 1½- to 1-inch | 1- to ¾-inch | ¾- to ½-inch |
| **Soft Material** | | | | |
| Number of samples | 3 | 25 | 28 | 18 |
| Loss: | | | | |
| Minimum ....percent | 13.5 | 2.5 | 2.5 | 1.4 |
| Maximum ....do | 22.0 | 29.9 | 21.4 | 20.8 |
| Average ....do | 19.0 | 11.2 | 10.4 | 9.6 |
| **Hard Material** | | | | |
| Number of samples | 5 | 19 | 21 | 9 |
| Loss: | | | | |
| Minimum ....percent | 1.0 | 2.0 | 2.5 | 1.4 |
| Maximum ....do | 24.0 | 19.5 | 32.0 | 34.2 |
| Average ....do | 15.9 | 10.3 | 9.9 | 11.6 |

***Figure 3.—Hammers and scribes used in soft piece test. Left to right: 2-pound stone-mason's hammer, 1-pound tinner's hammer, 8-ounce tinner's hammer, 2-ounce tile-setter's hammer, brass scratch pencil, knife, and rubber mallet.***

light taps. Consideration was also given to the type of failure of a specimen under blows of a reasonably heavy hammer. It was thought that if the material were soft it would crush under the hammer, producing a large amount of powder with relatively few large fragments; hard material, on the other hand, would break to sharp-edged fragments with relatively little powdering. Of all these hand-hammer tests, none gave satisfactory results, and this type of test was discontinued.

Consideration was then given to an impact test using as the striker an article which would deform around the piece under test but still transmit stress to it. The articles considered for this application were a device known in some circles as a blackjack, and a mallet with a rubber head such as is used in removing dents from automobile bodies. A blackjack having a leather case filled with lead shot was tried, but after a few tests the leather broke and further consideration of this was discontinued. For a few very soft materials, the rubber mallet gave satisfactory results, but moderately soft materials of 1-inch size or larger could not be crushed with the mallet. This test was also discontinued.

### *Compression Tests*

The suitability of a compression test to identify soft pieces was tried. A small apparatus known as the Douglass stone meter [3] has been used for such a test, but the maximum load specified is only 75 pounds and this load will crush only the weakest specimens. This apparatus is shown in figure 4. The use of a hydraulic compression testing machine was then proposed. In the method considered, an attempt was made to apply load to the particle through ½-inch steel balls. For pieces of irregular shape, this was very difficult to perform, and flat-faced steel cylinders of ½-inch diameter were substituted for the balls. The pieces under test were ground on a lap to secure bearing faces, and were tested with the least dimension in a vertical position. Load was applied at a slow but predetermined rate and failure determined to the nearest 10 pounds. Each sample tested contained from 20 to 100 pieces.

The results obtained are given in table 6. It will be observed that no well-defined separation between hard and soft materials is obtained. Study of the pieces under load revealed one interesting feature. In testing one material—a shale which occurs in rather thin pieces—it was noticed that the portion of the piece not in contact with the loading cylinders fell away at a relatively low load, but the material between the loading cylinders became more compact as the loading continued. In one case, this material was loaded to 35,000 pounds or almost 180,000 pounds per square inch. It is apparent that this type of loading is unsuitable for thin specimens of soft material and that the test does not separate hard from soft material.

### *Freezing and Thawing Test*

The freezing and thawing test was used to determine whether any relationship could be established between the results of this test and the hardness of the materials considered. The samples were immersed in water for 24 hours prior to freezing, frozen at about 15° F. in water, and thawed at about 80° F. A 24-hour cycle was used. After 10 cycles of the test, the samples were examined. With only a few exceptions, this short test failed to differentiate between hard and soft materials. The test was then resumed for another 10 cycles. After the twentieth cycle, the samples were dried, sieved on a sieve with openings having linear dimensions one-half the size of those in the original retaining sieve, and the material passing the sieve expressed as a percentage of the weight of the original sample. The half-size sieves were used rather than the original sieves to prevent the inclusion, in the loss, of those pieces which might pass the original retaining sieve due only to minor flaking or chipping. Results of these tests are given in table 7.

***Figure 4.—Douglass stone meter in use. To the right are the toughness machines with the 1⅞-inch and 2½-inch balls.***

[3] Douglass stone meter described in Method T-8-24, *Standard Specifications for Highway Materials and Methods of Sampling and Testing, 1938;* American Association of State Highway Officials, p. 154. This method has been withdrawn by the Association.

**Table 6.—*Use of the compression machine for identification of hard and soft materials (load applied through flat faces of ½-inch diameter)***

| Item | Size of pieces | | | |
|---|---|---|---|---|
| | 2- to 1½-inch | 1½- to 1-inch | 1- to ¾-inch | ¾- to ½-inch |
| SOFT MATERIAL | | | | |
| Number of samples | 4 | 9 | 20 | 8 |
| Compressive strength: | | | | |
| Minimum ... lb | 1,130 | 540 | 120 | 120 |
| Maximum ... do | 2,910 | 2,970 | 2,770 | 3,530 |
| Average ... do | 1,840 | 1,270 | 860 | 1,010 |
| HARD MATERIAL | | | | |
| Number of samples | 5 | 10 | 13 | 3 |
| Compressive strength: | | | | |
| Minimum ... lb | 500 | 860 | 690 | 480 |
| Maximum ... do | 3,460 | 2,950 | 3,250 | 1,290 |
| Average ... do | 1,890 | 1,830 | 1,750 | 860 |

**Table 7.—*Use of freezing and thawing (20 cycles) for identification of hard and soft material***

| Item | Size of pieces | | | |
|---|---|---|---|---|
| | 2- to 1½-inch | 1½- to 1-inch | 1- to ¾-inch | ¾- to ½-inch |
| SOFT MATERIAL | | | | |
| Number of samples | 1 | 12 | 21 | 11 |
| Loss passing ½-size sieve: | | | | |
| Minimum ... percent | | 3.1 | 5.0 | 9.4 |
| Maximum ... do | | 92.8 | 93.0 | 92.2 |
| Average ... do | 9.2 | 26.1 | 42.5 | 51.5 |
| HARD MATERIAL | | | | |
| Number of samples | 4 | 11 | 14 | 3 |
| Loss passing ½-size sieve: | | | | |
| Minimum ... percent | 2.7 | 0.6 | 0.4 | 5.4 |
| Maximum ... do | 31.6 | 18.2 | 51.4 | 25.3 |
| Average ... do | 11.8 | 5.0 | 11.4 | 13.1 |

Considerable overlapping of test results is found, but the average values are separated so widely that they indicate some possibilities in the use of this method for the identification of hard and soft aggregates. The main objections to this test are the length of time required and the expense and nonportability of the apparatus. The test appears to be of some value for use in research investigations, but it hardly seems suitable for a routine testing procedure.

### *Revision of the Compression Test*

Shortly after this investigation had been started, the entry of the United States into World War II required that the work be discontinued. Due to lack of storage space, only a few of the samples originally received were kept intact and, consequently, a suitable correlation between the two portions of the investigation cannot be established without repeating a large amount of work.

When the investigation was resumed in 1945, a study of the then existing data indicated that possibly a fair trial had not been given to the compression test. In the previous work, plane and approximately parallel faces had been ground on each piece tested, and the pieces loaded between flat-faced cylinders of ½-inch diameter. The labor of grinding faces on 50 to 100 pieces of each size in each sample tested was considered objectionable, and some means of testing pieces of any shape without preliminary grinding was sought. Trials were made of a number of different types of loading devices. After considerable work, a loading device consisting of a single-point upper contact and a three-point lower support was adopted. As shown in figure 5, the upper contact consists of a short steel rod of ½-inch diameter, with a hemispherical end, which is fastened to the spherical bearing block of a hydraulic cube-testing machine. The lower bearing consists of three ½-inch diameter steel balls grouped together so that their surfaces are in contact, and welded to a small steel base. With this loading and support arrangement, most pieces of both regular and irregular shape can be placed in a stable position for the test.

To obtain values for use in identifying pieces of hard, sound aggregate, several hundred pieces of each size of three different materials were tested and the breaking load of each piece determined. From the data obtained, the following loads were selected as indicating hard materials:

| *Size of piece, inches* | *Load, pounds* |
|---|---|
| ⅜ to ½ | 200 |
| ½ to ¾ | 350 |
| ¾ to 1 | 500 |
| 1 to 1½ | 750 |
| 1½ to 2 | 1,100 |
| 2 to 2½ | 1,500 |

### *Tests of Commercial Gravels*

With the establishment of these tentative acceptance values for hard material, it was believed desirable to conduct tests on a number of different materials to determine whether the test would be found satisfactory. Only a few of the materials obtained in 1941 were still available, and these had been sampled so extensively that complete ranges in size of particle could not be obtained. To obtain samples for further tests, the National Sand and Gravel Association was requested to furnish samples of commercially produced gravels which would contain some soft material. To the samples received from the Association were added a number of gravels which had been submitted to the laboratory for routine tests. These samples were tested for soft-piece content using the compression test described above, the 20-cycle freezing and thawing test, and the Los Angeles abrasion test. In the last test, determinations of the percentage of wear were made at 100 and 500 revolutions and a ratio of the losses used as an expression of the amount of soft material in the sample.

***Figure 5.—Compression test for soft pieces, using a three-point support and a single-point load-bearing contact.***

The results of these tests are given in table 8. Inspection of the results discloses immediately that there is little agreement among the indications of the three methods of test. For some few samples, all three methods show the presence of appreciable amounts of soft material. In most cases, however, the three methods give different results. One reason for nonuniformity among the three methods is the variance of the unit of failure on which the test result depends. In the compression test, the pieces of the sample are tested separately, and the whole piece is discarded if it fails to meet the conditions of the test. In the Los Angeles abrasion test and in the freezing and thawing test, it is entirely possible that only a portion of a given particle may be included in the loss. Consequently, it is doubtful that any satisfactory agreement among different methods of test can be established unless the unit of failure is the same in each case.

Consideration of the values obtained in the compression test shown in table 8 indicates that the limits set for the identification of hard pieces are probably too severe. A review of the individual test results for each sample shows a very high percentage of failures in the smaller sizes of piece, and also an excessive percentage of failures for pieces which tend toward a flat shape. In this test, the point of application of the load is normally above a point equidistant from the point of support of each of the three balls in the lower bearing. With thin or flat pieces, this could result in flexure of the piece under test, and the failure would be by bending instead of by compression.

**Table 8.—*Soft-piece tests on commercially produced gravels***

| Sample No. | Los Angeles abrasion test: Loss at 100 revolutions | Los Angeles abrasion test: Loss at 500 revolutions | Los Angeles abrasion test: Ratio of losses [1] | Compression test: Percentage of soft material, by weight | Freezing and thawing test: Loss after 20 cycles |
|---|---|---|---|---|---|
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 67464 | 6.0 | 28.1 | 21.4 | | 27.4 |
| 67621 | 4.9 | 24.2 | 20.2 | | 10.4 |
| 67622 | 4.4 | 22.7 | 19.4 | | 10.3 |
| 67628 | 8.1 | 32.6 | 24.8 | | 9.1 |
| 67629 | 5.4 | 27.3 | 19.8 | | 9.3 |
| 67680 | 4.2 | 23.4 | 17.9 | | 6.8 |
| 67696 | 4.6 | 23.8 | 19.3 | | 7.5 |
| 67757 | 5.6 | 23.6 | 23.7 | 12.1 | 4.2 |
| 67858 | 7.3 | 26.4 | 27.7 | | 11.0 |
| 67909 | 5.6 | 23.3 | 24.0 | | 17.0 |
| 67910 | 4.2 | 25.0 | 16.8 | | 17.2 |
| 67954 | 6.1 | 27.8 | 21.9 | | 20.4 |
| 68516 | 5.6 | 26.5 | 21.1 | 15.6 | 11.2 |
| 68768 | 7.6 | 30.7 | 24.8 | 24.5 | 19.7 |
| 68769 | 5.4 | 26.3 | 20.5 | 19.5 | 6.5 |
| 68770 | 5.7 | 27.1 | 21.0 | 21.3 | 5.7 |
| 68771 | 4.1 | 21.3 | 19.2 | 14.4 | 7.6 |
| 68772 | 6.5 | 29.0 | 22.4 | 26.2 | 8.4 |
| 68773 | 5.3 | 26.6 | 19.9 | 23.7 | 3.8 |
| 68774 | 8.5 | 32.9 | 25.8 | 33.1 | 12.7 |
| 68775 | 6.8 | 30.8 | 22.1 | 18.8 | 8.9 |
| 68776 | 6.4 | 31.8 | 20.1 | 38.9 | 21.3 |
| 68777 | 7.4 | 32.4 | 22.8 | 29.8 | 29.2 |
| 68778 | 6.8 | 29.6 | 23.0 | 14.0 | 4.1 |
| 68779 | 5.8 | 25.5 | 22.8 | 23.7 | 2.4 |
| 68780 | 6.6 | 30.3 | 21.8 | 17.6 | 9.5 |

[1] Ratio of loss at 100 revolutions to loss at 500 revolutions.

### *Review of Methods of Test*

Late in 1946, several new methods of testing aggregates for content of soft pieces were suggested. These new methods included a scratch test using a scribe of yellow brass, and two abrasion tests. In one of the latter, the sample was placed in a canvas bag with a charge of steel balls and the bag dropped on or swung against an anvil a given number of times. In the other abrasion test, the sample alone was placed in a bag and subjected to blows delivered by a rubber-headed mallet, freely swung as shown in figure 6. In trying these methods, it was considered desirable to include in the program of tests some of the methods which had previously been used.

***Figure 6.—Bag and mallet test for soft pieces.***

The material used in these tests consisted of quartz gravel of a reasonably uniform hardness to which was added definite quantities of soft stone or gravel obtained from the remnants of the samples received in 1941. It seemed possible that the test operators might be influenced by the color of the different pieces and would unconsciously classify them on this basis, and suggestions were made that all the material be dyed to a uniform color, or the operators fitted with colored glasses. Both suggestions, after some consideration, were rejected and the difficulty overcome in part by the use of some soft material of nearly the same color as the base gravel. Furthermore, most of the tests made have definite end points, and the operator is not required to decide whether the material does or does not meet the conditions of the test.

Several changes in the test procedure as previously used were thought to be desirable. A brief description of each method follows.

*Method 1: Steel scratch test.*—Each piece was scratched with a sharp knife blade. The weight of the pieces identified as soft was reported as a percentage of the original weight of the sample.

*Method 2: Brass scratch test.*—Each piece was scratched with a pointed scribe prepared from ¼-inch diameter yellow brass rod. The results were reported as in method 1.

*Method 3: Light hammer test.*—The test piece was placed on an anvil in its most natural position of repose, held firmly with the fingers, and struck at the center of the upper face with the flat end of the tile-setter's hammer. The hammer was swung through an arc of about 6 inches using only a natural movement of the wrist. Softness was recognized by crushing or crumbling of the piece under test. A clean fracturing or splintering of the piece—that is, breaking into smaller but solid fragments without considerable powdering—was not considered indicative of softness. More than one blow was permitted if necessary to classify the piece properly. The results were reported as in method 1.

*Method 4: Rubber mallet test.* — This method followed the procedure given in method 3, but using a rubber mallet instead of the tile-setter's hammer.

*Method 5: Toughness test for gravel.*—The falling-ball apparatus previously described, and illustrated in figure 1, was used. The 2½-inch ball was dropped as follows:

| *Size of piece, inches* | *Height of fall, inches* |
|---|---|
| 1½ to 1 | 3 |
| 1 to ¾ | 2 |
| ¾ to ½ | 1 |

The test piece was held on the anvil and adjusted under light tapping of the free ball to a secure bearing. The free ball was then raised to the height indicated for the size of aggregate under test and allowed to fall on the piece. Softness of the piece was shown by crushing, powdering, or crumbling. The test result for each piece was reported as in method 1.

*Method 6: Toughness test for gravel.*—The procedure given in method 5 was repeated, using the apparatus containing the 1⅞-inch ball, and with heights of fall as follows:

| *Size of piece, inches* | *Height of fall, inches* |
|---|---|
| 1½ to 1 | 5 |
| 1 to ¾ | 3 |
| ¾ to ½ | 1 |

*Method 7: Rotary soft-piece test.*—The rotary machine previously described, and illustrated in figure 2, was operated at its slowest speed (about 110 r.p.m.). The pieces of the test sample were fed separately into the machine and all debris caught. The material passing the original retaining sieve was determined, and expressed as a percentage, by weight, of the original sample.

*Method 8: Douglass stone meter test.*—The stone meter was used with the following loads:

| *Size of piece, inches* | *Applied load, pounds* |
|---|---|
| 1½ to 1 | 125 (Maximum loading of spring) |
| 1 to ¾ | 75 |
| ¾ to ½ | 60 |

The results were reported as in method 1.

*Method 9: Compression test.*—The tests were made in the hydraulic testing machine with the one-point upper and three-point lower bearing surfaces, using the following loads:

| *Size of piece, inches* | *Applied load, pounds* |
|---|---|
| 1½ to 1 | 500 |
| 1 to ¾ | 350 |
| ¾ to ½ | 200 |

The piece tested was placed in its most stable position on the three-point support, and load applied without shock through the single-point contact on the upper surface of the specimen. Breakage of the specimen at a load below those indicated constituted failure. The results were reported as in method 1.

*Method 10: Bag abrasion method.*—A 1,000-gram sample was placed in a 10- by 14-inch canvas bag with an abrasive charge of five 1⅞-inch diameter cast-iron or steel balls. The neck of the bag was fastened securely to prevent loss of the sample. The bag was swung 100 times through a distance of 12 inches against an anvil. The sample was then removed from the bag and sieved on a No. 4 sieve. The material passing this sieve was expressed as a percentage of the original weight of the sample.

*Method 11: Bag and mallet method.*—A 1,000-gram sample was placed in a 6- by 9-inch canvas bag and the neck fastened securely to confine the sample in the least possible space. The bag was then placed on an anvil and struck 100 times with a rubber-headed mallet. The blows were distributed over the side of the bag, and after each tenth blow the bag was turned over to expose the lower side. The results were determined as in method 10.

*Method 12: Los Angeles abrasion test.*—Samples weighing 5,000 grams of each size of material were tested in the Los Angeles machine, with an abrasive charge of 12 steel balls weighing 5,000 grams. The percentage of wear was determined at 100 and 500 revolutions.

The results obtained in these tests are given in table 9. The values shown in the first line of the table are the percentages, by weight, of soft material which were added to the quartz gravel. The values given in the rest of the table, except for those of the Los Angeles abrasion tests, are the percentages by weight of soft material found by the test method indicated. The values given for the Los Angeles tests are the losses in percentages by weight obtained in the tests. The ratio of the losses at 100

**Table 9.—*Results of tests for soft pieces using prepared samples***

| Method | Percentage of soft pieces: Size of pieces, 1½- to 1-inch | 1- to ¾-inch | ¾- to ½-inch | Average |
|---|---|---|---|---|
| Soft pieces placed in material | 4.8 | 16.2 | 10.4 | 10.5 |
| Scratch hardness methods: | | | | |
| Steel scribe | 17.6 | 18.2 | 14.9 | 16.9 |
| Brass scribe | 4.8 | 16.3 | 10.6 | 10.5 |
| Impact methods: | | | | |
| 2-ounce hammer | 11.3 | 18.8 | 17.9 | 16.0 |
| Rubber mallet | 1.4 | 10.1 | 12.6 | 8.0 |
| Rotary machine | 14.6 | 10.6 | 10.9 | 12.0 |
| Toughness, 2½-inch ball | 10.2 | 34.1 | 21.1 | 21.8 |
| Toughness, 1⅞-inch ball | 20.1 | 22.0 | 10.2 | 17.4 |
| Compression method: | | | | |
| Douglass machine | 8.5 | 4.8 | 0.6 | 4.6 |
| 3-point support | 4.2 | 16.9 | 21.0 | 14.0 |
| Abrasion method: | | | | |
| Bag abrasion | 6.7 | 18.0 | 14.0 | 12.9 |
| Bag and mallet | 6.4 | 11.7 | 11.7 | 9.9 |
| Los Angeles machine: | | | | |
| Loss at 100 revolutions | 5.1 | 11.9 | 14.8 | — |
| Loss at 500 revolutions | 22.5 | 40.3 | 45.3 | — |
| Ratio, 100/500 | 22.7 | 29.5 | 32.7 | — |

and 500 revolutions has been thought to have some relation with the amount of soft material in the sample. A comparison between these values and the amounts of soft material actually added to the base gravel indicates that this test, as made on individual sizes of aggregate, does not furnish test results which are indicative of the amount of soft material in the sample.

The most favorable results obtained in this series of tests are those furnished by the brass scribe, the rotary soft-piece machine, and the bag and mallet test. In previous work, when the rotary machine was operated at a speed of 200 r.p.m., it had not given very significant results. Although much better results are obtained when the machine is operated at a slower speed, further consideration of this type of testing equipment was discontinued as the machine is not suitable for field use.

### *Bag and Mallet Test*

Some questions developed regarding the size of sample which would be most desirable in the bag and mallet method, and also how many tests should be made to obtain a test value representative of a given material. From a practical consideration, a sample of the size used appears to be about as large as is desired for readiness of handling. Should the material to be tested have a maximum size greater than 1½ inches, the size of the test sample must be increased and a larger bag be used. Considerable development work along this and other lines remains to be done before this method can be adopted for use. To determine the other feature of particular interest here—that is, the number of 1,000-gram samples which should be tested for a material with a maximum size of 1½ inches—another series of tests was made.

In these tests, a soft sandstone was added in definite quantities to a quartz gravel to prepare four aggregates containing 0, 4, 8, and 12 percent soft material. Each material, both the hard and soft, was graded uniformly from 1½- to ⅜-inch. After each aggregate had been prepared, it was mixed thoroughly and ten 1,000-gram samples taken for test. The attempt made here was to duplicate conditions which would exist if a sample of graded aggregate were tested by the bag and mallet method. Each sample was placed in a double canvas bag, one bag inside of the other, and struck 100 times with a rubber-headed mallet. The sample was then sieved on a No. 4 sieve, and the amount passing the sieve determined as well as the amount of soft material retained on the sieve.

**Table 10.—*Bag and mallet tests on prepared samples of quartz gravel containing soft sandstone***

| Sample No. | Amount of soft stone added to gravel: None, Loss | None, Cumulative average loss | 4 percent, Loss | 4 percent, Cumulative average loss | 8 percent, Loss | 8 percent, Cumulative average loss | 12 percent, Loss | 12 percent, Cumulative average loss |
|---|---|---|---|---|---|---|---|---|
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1 | 4.4 | 4.4 | 6.2 | 6.2 | 12.5 | 12.5 | 9.7 | 9.7 |
| 2 | 3.7 | 4.0 | 6.2 | 6.2 | 9.9 | 11.2 | 11.2 | 10.4 |
| 3 | 5.9 | 4.7 | 6.3 | 6.2 | 8.7 | 10.4 | 12.3 | 11.1 |
| 4 | 4.3 | 4.6 | 7.4 | 6.5 | 10.6 | 10.4 | 10.7 | 11.0 |
| 5 | 3.7 | 4.4 | 5.8 | 6.4 | 8.2 | 10.0 | 13.1 | 11.4 |
| 6 | 3.9 | 4.3 | 7.0 | 6.5 | 9.0 | 9.8 | 12.4 | 11.6 |
| 7 | 4.8 | 4.4 | 6.0 | 6.4 | 10.0 | 9.8 | 13.4 | 11.9 |
| 8 | 4.7 | 4.4 | 6.3 | 6.4 | 6.9 | 9.5 | 9.8 | 11.6 |
| 9 | 5.0 | 4.5 | 6.5 | 6.4 | 6.9 | 9.2 | 10.9 | 11.5 |
| 10 | 3.7 | 4.4 | 5.0 | 6.3 | 9.5 | 9.2 | 9.1 | 11.3 |

A summary of the results obtained is given in tables 10 and 11. In table 10, the percentage of loss for each sample tested is given, together with a cumulative average. For most aggregates, an average value obtained from tests of three samples is very nearly the same as the average for all ten samples of a kind tested. Of more importance, however, is the comparison of the amount of soft stone placed in the aggregate, the test result obtained, and the amount of soft stone remaining in the sample after the test, as shown in table 11. Tests of the base gravel show a loss of 4.4 percent. The results obtained in tests of the gravel containing 4 percent of soft stone show 6.3 percent loss but 2.0 percent of soft stone is left in the sample. This 6.3 percent loss then includes 2.0 percent of soft stone and 4.3 percent from the quartz gravel.

**Table 11.—*Percentage of soft stone remaining in sample after test,*[1] *and loss from gravel***

| Soft stone added to gravel | Cumulative average loss | Soft stone remaining | Loss from gravel |
|---|---|---|---|
| *Percent* | *Percent* | *Percent* | *Percent* |
| 0 | 4.4 | | 4.4 |
| 4 | 6.3 | 2.0 | 4.3 |
| 8 | 9.2 | 3.3 | 4.5 |
| 12 | 11.3 | 4.5 | 3.8 |

[1] Averages for 10 samples.

By a similar method of figuring, the test results for the aggregates containing 8 and 12 percent of soft stone include 4.5 and 3.8 percent, respectively, of the quartz gravel in the loss. Although it is granted that the quartz gravel may contain material of a friable nature, a comparison of the gravel and the sandstone used in these tests indicates that a satisfactory method of test should show a greater recovery of the soft material in the test results. The fact that from 38 to 50 percent of the soft sandstone placed in the sample remains there after the test shows definitely that the test as made is not satisfactory.

### *Brass Scratch Test*

In this investigation, considerable difficulty was encountered in trying to unify the conceptions offered by different authorities regarding a proper description of a soft piece, and much time and effort were spent to develop a satisfactory method of test for soft pieces. In addition to the various tests described here, many more fanciful tests were considered and, in some cases, plans for quite elaborate pieces of testing equipment were prepared. A few of these fanciful tests were tried but did not prove even remotely satisfactory. Possibly we have been trying to make something difficult of a really simple problem: The testing of aggregates to determine the presence and quantity of soft pieces—those which yield easily to physical pressure or are not resistant to cutting or wear.

Among all of the test methods considered, the most simple and direct is a scratch hardness test. This would not indicate the pieces which are unsound, or light-weight, or highly absorptive; or the pieces of chert which appear to be included by some authorities in the general classification of soft pieces. It would, however, show which pieces of the sample are actually soft, including those formed of a soft material and those which are so poorly bonded that the separate particles in the piece are easily detached from the mass.

A satisfactory test for scratch hardness was used in this investigation. It consists merely of scratching the material under test with a piece of yellow brass, as shown in figure 7. This brass will not scratch limestone of good quality, but it is hard enough to scratch badly weathered materials which may be objectionable for use in concrete. The brass used first in these tests consisted of a ¼-inch rod which has a Rockwell hardness of about B70. Later in this work, the thought of preparing a pencil with a brass rod replacing the lead was developed. For this purpose, drill-rod brass [4] of about 1/16-inch diameter was used. Efforts were made to obtain a Rockwell hardness value for this material, but the rod was too small to secure a satisfactory reading. For the purpose of this test, it is probable that minute distinctions in the hardness of the brass used is of little moment. Possibly it is sufficient to describe the material as hard, yellow brass.

[4] So called as it is obtainable in the same sizes as steel twist drills.

*Figure 7.—The scratch test, using a hard, yellow brass scribe "pencil" made with a drill-rod brass core encased in wood. This is the only test for soft aggregates suitable to both field and laboratory use.*

The test consists of separating the aggregate into different sizes, down to ⅜-inch, and determining the scratch hardness of a representative number of pieces of each size. With material of fairly uniform quality, 10 pieces of a size may be sufficient; but 50 or 100 pieces of a size may be required for heterogeneous materials. The weight of the pieces identified as soft is determined for each size, and a weighted average based on the grading of the sample is computed.

This test is for soft pieces only. If it is desired to limit the amount of other types of deleterious materials in aggregate, separate mention of these should be made in specifications.

The courtesy of the State highway departments and the National Sand and Gravel Association in furnishing samples for use in these tests is appreciated, as are the many valuable suggestions offered by Mr. T. R. Smith, and the assistance furnished by him and the other employees of the laboratories of the Bureau of Public Roads.

# Errata

In order to rectify a printer's error, page 121 of the February 1951 issue of PUBLIC ROADS (Vol. 26, No. 6) was reprinted with a heading "Errata Sheet" and distributed to all subscribers. A number of inquiries since received indicate that the purpose of this was in some cases misunderstood. The error involved a mix-up of text on page 121, under the caption "Part IV—Over-All Intersection Capacity." As originally printed, the first and third columns were inadvertently interchanged, so that the lower portion of the page must be read (by columns) from right to left.

The printer also unfortunately turned chart 4, on page 128, to read from the left edge of the page instead of the right edge, thus considerably impairing the facility of use of the chart series.

While these errors occurred after final proofing and were beyond the control of the editorial staff of PUBLIC ROADS, they nevertheless greatly regret the inconvenience caused thereby.

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Bureau of Public Roads, Washington 25, D. C.

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Act V.—Uniform Act Regulating Traffic on Highways. 20 cents.
Model Traffic Ordinance. 15 cents.

## MISCELLANEOUS PUBLICATIONS

Bibliography of Highway Planning Reports. 30 cents.
Construction of Private Driveways (No. 272MP). 10 cents.
Economic and Statistical Analysis of Highway Construction Expenditures. 15 cents.
Electrical Equipment on Movable Bridges (No. 265T). 40 cents.
Federal Legislation and Regulations Relating to Highway Construction. 40 cents.
Financing of Highways by Counties and Local Rural Governments, 1931–41. 45 cents.
Guides to Traffic Safety. 10 cents.
Highway Accidents. 10 cents.
Highway Bond Calculations. 10 cents.
Highway Bridge Location (No. 1486D). 15 cents.
Highway Capacity Manual. 65 cents.
Highway Needs of the National Defense (House Document No. 249). 50 cents.
Highway Practice in the United States of America. 50 cents.
Highway Statistics, 1945. 35 cents.
Highway Statistics, 1946. 50 cents.
Highway Statistics, 1947. 45 cents.
Highway Statistics, 1948. 65 cents.
Highway Statistics, 1949. 55 cents.
Highway Statistics, Summary to 1945. 40 cents.
Highways of History. 25 cents.
Identification of Rock Types. 10 cents.
Interregional Highways (House Document No. 379). 75 cents.
Legal Aspects of Controlling Highway Access. 15 cents.
Local Rural Road Problem. 20 cents.
Manual on Uniform Traffic Control Devices for Streets and Highways. 50 cents.
Mathematical Theory of Vibration in Suspension Bridges. $1.25.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft. $1.75.
Public Control of Highway Access and Roadside Development. 35 cents.
Public Land Acquisition for Highway Purposes. 10 cents.
Roadside Improvement (No. 191MP). 10 cents.
Selected Bibliography on Highway Finance. 55 cents.
Specifications for Construction of Roads and Bridges in National Forests and National Parks (FP-41). $1.50.
Taxation of Motor Vehicles in 1932. 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces. 10 cents.
Transition Curves for Highways. $1.25.

***Single copies of the following publications are available to highway engineers and administrators for official use, and may be obtained by those so qualified upon request addressed to the Bureau of Public Roads. They are not sold by the Superintendent of Documents.***

## ANNUAL REPORTS

*(See also adjacent column)*

Public Roads Administration Annual Reports:
1943. 1944. 1945.

## MISCELLANEOUS PUBLICATIONS

Bibliography on Automobile Parking in the United States.
Bibliography on Highway Lighting.
Bibliography on Highway Safety.
Bibliography on Land Acquisition for Public Roads.
Bibliography on Roadside Control.
Express Highways in the United States: a Bibliography.
Indexes to PUBLIC ROADS, volumes 17–19, 22, and 23.
Road Work on Farm Outlets Needs Skill and Right Equipment.

# STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF FEBRUARY 28, 1951

(Thousand Dollars)

| STATE | UNPROGRAMMED BALANCES | ACTIVE PROGRAM: PROGRAMMED ONLY | | | ACTIVE PROGRAM: PLANS APPROVED, CONSTRUCTION NOT STARTED | | | ACTIVE PROGRAM: CONSTRUCTION UNDER WAY | | | ACTIVE PROGRAM: TOTAL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Cost | Federal Funds | Miles | Total Cost | Federal Funds | Miles | Total Cost | Federal Funds | Miles | Total Cost | Federal Funds | Miles |
| Alabama | $18,088 | $10,575 | $5,344 | 214.9 | $6,542 | $3,327 | 129.5 | $14,783 | $7,107 | 352.5 | $31,900 | $15,778 | 696.9 |
| Arizona | 274 | 7,709 | 5,445 | 186.0 | 353 | 243 | 2.0 | 6,610 | 4,734 | 120.1 | 14,672 | 10,422 | 308.1 |
| Arkansas | 6,990 | 8,515 | 4,709 | 238.2 | 3,073 | 1,703 | 97.0 | 15,321 | 7,582 | 404.8 | 26,909 | 13,994 | 740.0 |
| California | 6,040 | 57,266 | 17,167 | 273.3 | 9,774 | 4,948 | 44.2 | 52,113 | 24,768 | 262.2 | 119,153 | 46,883 | 579.7 |
| Colorado | 3,957 | 6,231 | 3,527 | 223.6 | 2,921 | 1,522 | 64.0 | 11,152 | 6,193 | 241.3 | 20,304 | 11,242 | 528.9 |
| Connecticut | 3,668 | 7,664 | 3,888 | 21.3 | 3,659 | 2,025 | 1.7 | 6,353 | 3,485 | 10.6 | 17,676 | 9,398 | 33.6 |
| Delaware | 2,185 | 1,014 | 608 | 22.5 | 19 | 8 | | 6,449 | 3,153 | 38.4 | 7,482 | 3,769 | 60.9 |
| Florida | 7,862 | 8,222 | 4,339 | 153.4 | 9,242 | 4,496 | 176.6 | 17,707 | 8,755 | 392.1 | 35,171 | 17,590 | 722.1 |
| Georgia | 8,160 | 12,985 | 6,668 | 243.0 | 11,898 | 5,071 | 91.9 | 28,555 | 14,135 | 694.4 | 53,438 | 25,874 | 1,029.3 |
| Idaho | 5,583 | 8,839 | 5,579 | 271.6 | 2,530 | 1,754 | 121.1 | 6,116 | 3,260 | 122.1 | 17,485 | 10,593 | 514.8 |
| Illinois | 21,364 | 53,518 | 28,307 | 506.5 | 24,055 | 12,443 | 220.8 | 47,441 | 22,880 | 277.5 | 125,014 | 63,630 | 1,004.8 |
| Indiana | 13,154 | 37,044 | 18,421 | 183.7 | 4,648 | 2,329 | 28.6 | 18,424 | 9,353 | 96.2 | 60,116 | 30,103 | 308.5 |
| Iowa | 3,388 | 14,498 | 6,810 | 750.9 | 10,284 | 5,090 | 301.7 | 11,310 | 5,731 | 291.7 | 36,092 | 17,631 | 1,344.3 |
| Kansas | 7,721 | 11,011 | 5,262 | 1,044.8 | 5,601 | 2,801 | 376.9 | 8,376 | 4,187 | 493.8 | 24,988 | 12,250 | 1,915.5 |
| Kentucky | 3,005 | 21,989 | 10,846 | 264.3 | 3,364 | 1,686 | 57.1 | 17,456 | 8,616 | 302.0 | 42,809 | 21,148 | 623.4 |
| Louisiana | 7,656 | 14,456 | 6,870 | 111.4 | 8,463 | 3,984 | 55.5 | 21,533 | 11,363 | 242.4 | 44,452 | 22,217 | 409.3 |
| Maine | 4,280 | 5,216 | 2,764 | 65.6 | 1,697 | 889 | 7.2 | 6,659 | 3,538 | 68.7 | 13,572 | 7,191 | 141.5 |
| Maryland | 5,296 | 4,576 | 2,265 | 23.2 | 3,822 | 1,481 | 14.1 | 11,138 | 5,099 | 39.7 | 19,536 | 8,845 | 77.0 |
| Massachusetts | 3,677 | 14,879 | 6,640 | 7.3 | 1,458 | 529 | | 65,113 | 32,328 | 61.9 | 81,450 | 39,497 | 69.2 |
| Michigan | 11,003 | 18,424 | 9,121 | 524.4 | 11,780 | 6,377 | 207.9 | 39,759 | 16,197 | 275.2 | 69,963 | 31,695 | 1,007.5 |
| Minnesota | 6,034 | 15,689 | 8,219 | 1,382.4 | 3,075 | 1,963 | 114.9 | 16,791 | 8,845 | 276.8 | 35,555 | 19,027 | 1,774.1 |
| Mississippi | 9,373 | 9,109 | 4,747 | 345.7 | 8,161 | 4,290 | 229.9 | 5,871 | 2,870 | 178.3 | 23,141 | 11,907 | 753.9 |
| Missouri | 12,956 | 23,668 | 12,429 | 690.2 | 14,338 | 7,752 | 351.6 | 27,541 | 13,985 | 369.5 | 65,547 | 34,166 | 1,411.3 |
| Montana | 10,106 | 13,472 | 6,887 | 443.4 | 3,721 | 2,197 | 80.5 | 9,501 | 5,703 | 202.5 | 26,694 | 14,787 | 726.4 |
| Nebraska | 8,635 | 16,585 | 8,628 | 571.4 | 7,033 | 3,479 | 217.8 | 9,298 | 4,947 | 253.8 | 32,916 | 17,054 | 1,043.0 |
| Nevada | 5,738 | 2,271 | 1,873 | 33.0 | 928 | 775 | 65.3 | 3,496 | 2,883 | 113.8 | 6,695 | 5,531 | 212.1 |
| New Hampshire | 3,145 | 2,591 | 1,472 | 18.9 | 443 | 210 | 3.7 | 4,555 | 2,263 | 39.4 | 7,589 | 3,945 | 62.0 |
| New Jersey | 6,793 | 5,892 | 2,946 | 7.4 | 3,048 | 1,522 | 4.2 | 18,862 | 8,702 | 21.6 | 27,802 | 13,170 | 33.2 |
| New Mexico | 4,513 | 4,376 | 2,800 | 88.8 | 857 | 552 | 18.7 | 9,416 | 6,008 | 262.8 | 14,649 | 9,360 | 370.3 |
| New York | 47,223 | 56,400 | 28,998 | 153.5 | 17,012 | 7,798 | 42.9 | 106,555 | 49,795 | 200.3 | 179,967 | 86,591 | 396.7 |
| North Carolina | 8,692 | 11,096 | 5,439 | 278.0 | 8,626 | 3,932 | 147.2 | 22,995 | 11,087 | 529.9 | 42,717 | 20,458 | 955.1 |
| North Dakota | 5,020 | 8,465 | 4,371 | 1,254.2 | 5,216 | 2,616 | 405.0 | 4,849 | 2,403 | 408.1 | 18,530 | 9,390 | 2,067.3 |
| Ohio | 15,836 | 20,415 | 9,561 | 222.9 | 18,376 | 10,175 | 203.9 | 71,424 | 35,484 | 267.3 | 110,215 | 55,220 | 694.1 |
| Oklahoma | 2,077 | 21,834 | 10,268 | 384.4 | 6,808 | 3,575 | 83.7 | 24,068 | 11,815 | 440.2 | 52,710 | 25,658 | 908.3 |
| Oregon | 2,302 | 3,823 | 2,238 | 56.2 | 7,653 | 3,922 | 78.2 | 10,555 | 6,094 | 158.4 | 22,031 | 12,254 | 292.8 |
| Pennsylvania | 21,010 | 7,825 | 3,823 | 15.8 | 11,314 | 5,510 | 15.7 | 80,533 | 39,803 | 227.7 | 99,672 | 49,136 | 259.2 |
| Rhode Island | 1,769 | 6,340 | 3,170 | 45.0 | 1,090 | 544 | 7.1 | 13,175 | 6,691 | 10.0 | 20,605 | 10,405 | 62.1 |
| South Carolina | 5,396 | 8,462 | 4,370 | 227.5 | 2,877 | 1,440 | 58.2 | 7,663 | 4,032 | 216.5 | 19,002 | 9,842 | 502.2 |
| South Dakota | 1,154 | 13,829 | 7,952 | 1,126.8 | 3,240 | 1,862 | 231.1 | 8,378 | 5,177 | 610.1 | 25,447 | 14,991 | 1,968.0 |
| Tennessee | 7,883 | 12,273 | 5,824 | 271.4 | 5,393 | 2,772 | 101.7 | 18,975 | 8,743 | 323.9 | 36,641 | 17,339 | 697.0 |
| Texas | 13,858 | 8,409 | 4,292 | 196.3 | 15,256 | 7,717 | 167.4 | 46,889 | 22,196 | 895.8 | 70,554 | 34,205 | 1,259.5 |
| Utah | 4,903 | 3,089 | 2,259 | 71.0 | 1,488 | 1,102 | 36.9 | 4,484 | 3,250 | 140.4 | 9,061 | 6,611 | 248.3 |
| Vermont | 1,006 | 4,577 | 2,410 | 63.2 | 891 | 449 | 8.1 | 4,236 | 2,077 | 28.7 | 9,704 | 4,936 | 100.0 |
| Virginia | 10,160 | 19,631 | 9,727 | 396.6 | 5,910 | 2,945 | 197.1 | 14,249 | 6,943 | 238.6 | 39,790 | 19,615 | 832.3 |
| Washington | 6,520 | 6,893 | 2,446 | 71.5 | 1,602 | 836 | 19.0 | 21,113 | 10,112 | 127.3 | 29,608 | 13,394 | 217.8 |
| West Virginia | 5,316 | 13,211 | 5,242 | 92.1 | 4,512 | 2,257 | 50.1 | 9,212 | 4,659 | 96.7 | 26,935 | 12,158 | 238.9 |
| Wisconsin | 9,295 | 28,031 | 14,698 | 762.6 | 3,907 | 1,889 | 94.5 | 13,113 | 6,498 | 313.4 | 45,051 | 23,085 | 1,170.5 |
| Wyoming | 1,530 | 1,772 | 1,151 | 28.7 | 4,141 | 2,694 | 109.4 | 6,082 | 3,745 | 163.0 | 11,995 | 7,590 | 301.1 |
| Hawaii | 2,296 | 7,716 | 3,336 | 14.3 | 2,193 | 781 | 10.6 | 6,138 | 2,498 | 18.5 | 16,047 | 6,615 | 43.4 |
| District of Columbia | 3,951 | 3,960 | 1,980 | 4.1 | 166 | 83 | .9 | 1,557 | 971 | .9 | 5,683 | 3,034 | 5.9 |
| Puerto Rico | 3,635 | 13,161 | 6,027 | 66.0 | 855 | 377 | 3.5 | 8,128 | 3,778 | 33.7 | 22,144 | 10,182 | 103.2 |
| TOTAL | 391,476 | 699,496 | 344,163 | 14,713.2 | 295,313 | 150,722 | 5,156.6 | 1,022,070 | 506,521 | 11,955.5 | 2,016,879 | 1,001,406 | 31,825.3 |